

SSD94 D 0218
LDTPS-TP-1

**Test Plans
Lightweight Durable TPS
Tasks 1, 2, 4, 5, and 6**

Cooperative Agreement NCC2-9003

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Foreword:

The document provided contains the Detailed Test Plans for SSTO Lightweight Durable TPS (Task 1, 2, 4, 5, & 6). The format of this document is displayed in the "Test Plan Index" on the following page. As each Task progresses, its Detailed Test Plan and its associated appendices will be maintained as "stand-alone" documents.

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Detail Test Plan - DTP 6446-801
Task 1 - Development of Fluted-Core Flexible Blankets

NRA8-12 - Advanced Structures and TPS Technologies
NCC2-9003 - Cooperative Agreement
TA-3 - Lightweight Durable Thermal Protection System

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Draft - July 27, 1994

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1.0 OBJECTIVE

The objective of this task is to develop the fluted core flexible blankets, also referred to as the Tailorable Advanced Blanket Insulation (TABI), to a technology readiness level (TRL) of 6. This task is one of the six tasks under TA 3, Lightweight Durable TPS study, of the Single Stage to Orbit (SSTO) program. The purpose of this task is to develop a durable and low maintenance flexible TPS blanket material to be implemented on the SSTO vehicle.

2.0 BACKGROUND

This task is divided into 6 subtasks. This detail test plan (DTP) begins with a general objective section, a general background section and a general requirement section for the entire task, followed by details of each of the subtasks which contain introduction, applicable documents, detailed requirements, fabrication / test article description, fabrication / test procedures, sample data sheet, equipment, sketches / schematics and schedule. Some of the subtasks are fabrication tasks and the sections are modified to reflect the nature of the subtask. In subtasks which require testing of the material, DTP of the test will be referenced and attached to in the Appendix section.

TABI is a next generation flexible TPS blanket material concept developed by NASA Ames a few years ago. It consists of 3-D fluted core structure integrally woven with high temperature ceramic yarns and the flutes filled with high temperature insulative ceramic material. NASA Ames awarded a contract to Woven Structures to weave various shapes of fluted cores, using various types of ceramic yarns. The weaving know-how, however, has since been lost due to contract cancellation and a change of Woven Structures ownership. The end result is that TABI is not commercially available.

Advanced Flexible Reusable Surface Insulation (AFRSI) on the Shuttle orbiter has demonstrated the weight and thermal advantages of flexible blanket TPS. However, due to the irregular surface configuration of AFRSI and its maximum-temperature limitation, its application is limited to upper surfaces of the vehicle. TABI's list of attractive properties, on the other hand, include high temperature capability, smooth aerodynamic surfaces, ease of installation / replacement and durability. These properties make TABI an attractive TPS candidate for the SSTO vehicle.

Since the original supplier of the TABI woven fabric configuration no longer exists, the primary goal of this task is to reestablish a commercial source for the TABI fabric structures required for the test articles of this program. The development of insulation installation procedures and the characterization of the resulting flexible thermal blanket are additional goals of this task.

The task is divided into 6 subtasks. They include developing the weaving of the TABI, batting insulation insertion techniques, the study for a strong, durable surface architecture, the evaluation and material characterization of the finished TABI composite, and the processing and installation procedures for the TABI blankets to be implemented on the SSTO vehicle.

3.0 GENERAL REQUIREMENT

3.1 Documentation

3.1.1 Detailed test procedure (DTP)

All testing will be conducted in accordance with this test procedure.

3.1.2 Laboratory Notebook

A Laboratory Notebook will be maintained by the Rockwell Responsible Test Engineer (RTE) depicting a complete test history. Test article configuration, instrumentation, test anomalies and all other pertinent data and information will be recorded.

3.1.3 Test Report

The test agency will issue a Laboratory Test Report (LTR). The test report will depict the complete test program, instrumentation, test procedures and results, test setup, photographs, test data and any other pertinent information.

3.2 Test Facility

Test equipment and facilities will be utilized at both government and industry facilities. Appropriate facilities will be selected to simulate the interaction of identified adverse environments with specific TPS specimens fabricated in Task 4. Test facilities which have been identified are listed below.

- NASA-Ames arc jet facilities, 60 and 20 MW facilities
- NASA-Ames light gas gun
- AFWL rain impact facility
- Rockwell cryogenic tank facility for ice/frost testing
- Rockwell rain/wind facility
- Rockwell salt spray environment facility
- Rockwell vibroacoustic facility
- Rockwell radiant heat facility

Schedules and test requirements are defined in the detailed test description section of this document.

3.3 Instrumentation

All measurement instrumentation shall be calibrated and have a decal showing a valid calibration date. A list of all test instrumentation will be maintained in a Laboratory Notebook.

3.4 Test Conduct

The test program will be conducted under the direction of the task leader or a designated representative.

4.0 SUBTASK DESCRIPTION

This task is divided into six subtasks as listed below. The subtasks will be described in details in Sections 4.1 through 4.6.

- Fabric Structure development (4.1)
- Insulation material development (4.2)
- Composite development (4.3)
- Surface architecture (4.4)
- Finished composite evaluation (4.5)
- Composite processing (4.6)

4.1 Fabric Structure Development

4.1.1 Introduction

This sub-task involves development of all the weaving for TABI. Weaving will be subcontracted by Rockwell to a weaver on task-by-task basis. Three ceramic materials will be used: Nicalon, Tyranno, and Nextel 440. The plan is to reestablish the triangular fluted-core blanket concept by producing Nicalon TABI, followed by development of Tyranno and Nextel 440 TABI. Part of the objective is to achieve a durable, strong TABI outer mold line (OML) surface which will endure the environment without the protection of ceramic coatings. The first approach is to select three different, strongest weave architectures known to the fabric industry, to obtain a durable, strong TABI OML surface. The second approach is to develop methods to attach a metallic foil to the TABI OML surface. The last TABI article will have metallic yarns woven into the surface of TABI which will provide a means for brazing the metallic foil to the TABI.

4.1.2 Applicable Documents

- Proposal to NRA8-12 - Advanced Structures and TPS Technologies.
- Cooperative Agreement - NCC2-9003
- NASA Ames, "TABI Procurement Specification, #9SB-90001-XR16"
- Rockwell, Statement of Work for Procuring TABI, June 1994.
- Calamito, D.P., "Development of Tailorable Advanced Blanket Insulation for Advanced Space Transportation Systems," NASA Contractor Report 177444, Contract NAS2-12253, April 1987
- Calamito, D.P., "Tailorable Advanced Blanket Insulation Using Aluminoborosilicate and Alumina Batting," NASA Contractor Report 177527, Contract NAS2-112693, July 1989
- Sawko, P.M., "Flexible Thermal Protection Materials,"
- Sawko, P.M., "Tailorable Advanced Blanket Insulation,"
- Sawko, P.M. and Tran D., "Effects of Weave Architecture on Aeroacoustic Performance of Ceramic Insulation Blankets," Journal of Advanced Materials, p51-57, Oct. 1993
- Sawko, P.M., "Thermal Insulation Blanket Material," NASA Contractor Report 166367, Contract NAS2-11094, June 1982
- Falstrup, D., "Double Layered Tailorable Advanced Blanket Insulation," NASA Contractor Report 1666000, Contract NAS2-11351, May 1983
- Pusch, R.H., "Thermal Blanket Insulation for Advanced Space Transportation Systems," NASA Contractor Report 177341, Contract NAS2-11718, Feb., 1985

4.1.3 Requirements

This subtask is a fabrication task. The TABI material to be delivered by the weaver will be inspected per the NASA Ames specification, "TABI Procurement Specification #9SP-90001-XR16". Tests to evaluate the qualification and performance of the articles will be described in Section 4.5 "Finished Composite Evaluation".

4.1.4 Fabrication/Test Article Description

Total of eight scheduled deliveries from the weaver are to be made as listed below.

- Eight sq. ft. (24" x 48" x 0.5") of Nicalon TABI per NASA Ames specification "TABI Procurement Specification #9SP-90001-XR16", angle interlock OML surface.
- Sixteen sq. ft. (24" x 96" x 1") of Nicalon TABI, same configuration as #1 except 1" flute height. instead of 0.5".
- Ten sq. ft. (24" x 60" x 1") of first strong weave configuration using Tyranno
- Ten sq. ft. (24" x 60" x 1") of second strong weave configuration using Tyranno
- Ten sq. ft. (24" x 60" x 1") of third strong weave configuration using Tyranno
- Sixty sq. ft. (24" x 360" x 1") of selected strongest weave configuration Tyranno TABI
- Twenty sq. ft. (24" x 120" x 1") of the selected strongest weave configuration Nextel 440 TABI
- Twenty sq. ft. (24" x 120" x 1") of (either Tyranno or Nextel 440) TABI with metallic yarn woven into surface to provide brazing medium for metallic foil attachment

4.1.5 Fabrication Development/Test Procedures

4.1.5.1 First Nicalon TABI

One piece of 8 sq. ft. (24" x 48" x 0.5") of TABI to be fabricated with Nicalon 600 denier yarns per Ames specification "TABI Procurement Specification, #9SB-90001-XR16", with triangular fluted cores and angle interlock OML surface. The purpose of this article is to demonstrate the ability to weave TABI. The Nicalon yarns (produced by Nippon Carbon and distributed by Dow Corning in the U.S.) are provided by NASA Ames in this program. The fluted core concept was successfully demonstrated by weaving with Nicalon and some other ceramic materials in the previous programs, and Nicalon was one of the materials that has the best properties and performance. Total of 40 pounds of Nicalon fibers were requested by the weaver, Textile Product Incorporated (TPI), to fabricate both the first and second Nicalon TABI articles. It's estimated to take 3 months to complete the first Nicalon TABI. The Nicalon yarns will be rayon served to be protected during the weaving process.

This article will be evaluation per the NASA Ames specification, arc jet, mini wind tunnel, guarded hot plate, and vibroacoustic testing after the batting is inserted and the TABI composite heat cleaned. The go-ahead to fabricate the second article of 1" height Nicalon TABI will be based on the performance of this article. The details of the testing are discussed in Section 4.5.

4.1.5.2 *Second Nicalon TABI*

One piece of 16 sq. ft. (24" x 96" x 1") of Nicalon TABI will be fabricated. The purposes of this article are to scale the Nicalon TABI flute height from 0.5" to 1" and also to obtain additional material for evaluation. One month is estimated for the fabrication of this article.

Tests TBD will be performed on this TABI. Details are discussed in Section 4.5.

4.1.5.3 *Three Tyranno TABI with Different Weaves*

Ten sq. ft. (24" x 60" x 1") of each of 3 different weave configuration Tyranno TABI (total of 30 sq. ft.) are to be fabricated. Rockwell is to research and purchase the appropriate Tyranno yarns. Ube Industries is the Japanese manufacturer of the material. The U.S. distributor is Textron Specialty Materials. Study and research is to be performed to select three strongest (or tightest) weaves for fabrics. The purpose of this task is to produce TABI with Tyranno yarn and to develop a strong OML fabric weave which does not require the protection of ceramic coatings. The black color of Tyranno and Nicalon, which provides high emittance, gives them an advantage over other ceramic yarns. Tyranno is very similar to Nicalon in composition except it has titanium in addition to carbon, and silicon. It has a smaller diameter than Nicalon and was assumed to be less health hazardous than Nicalon. It is estimated that two months will be required to fabricate each of the three different weaves Tyranno TABI.

Mini wind tunnel, air impingement (for screening purpose), and arc jet tests are to be performed to determine the strongest weave configuration before proceeding to fabricate the remaining articles.

4.1.5.4 *Strongest Weave Tyranno TABI*

Sixty sq. ft. (24" x 360" x 1") of selected strongest weave configuration Tyranno TABI will be fabricated. The purpose of this task is to provide the strongest weave for evaluation. Again, it is estimated that two months will be required for the fabrication of this article.

A series of tests (detailed in 4.5) will be performed to evaluate the performance of this strongest weave Tyranno TABI.

4.1.5.5 *Nextel 440 TABI*

Twenty sq. ft. (24" x 120" x 1") of the selected strongest weave configuration TABI will be woven with Nextel 440. The purpose of this task is to produce Nextel 440 TABI for comparative evaluation with Tyranno and Nicalon TABI. The schedule is three months for the delivery of this article.

Tests to evaluate the performance of Nextel 440 TABI will be determined later based on the performance of the uncoated strongest weave Tyranno.

4.1.5.6 *TABI with Metallic Yarn Woven into OML Surface*

Twenty sq. ft. (24" x 120" x 1") of either Tyranno or Nextel 440 TABI with metallic yarn woven into surface to provide brazing medium to metallic foil attachment will be fabricated. The configuration is also referred to as DuraTABI. The estimated time is three months to complete the weaving.

Tests TBD will be performed to evaluate the concept of DuraTABI (see Section 4.5).

4.1.6 Fabrication Sample Data Sheets

The weaver is to record basic properties. Table 4-I is a sample data sheet.

Table 4-I Basic Properties of TABI

Properties		Target Value	Measured Value
Fabric Yarn Count			
Top Face	Warp ends / inch	4 layers each 28.0 epi, +-2	
	Fill, picks / inch	3 layers each 28.0 ppi, +-2	
Ribs	Warp ends / inch	28.0 epi, +-2	
	Fill, picks / inch	26.5 ppi, +-2	
Bottom Face	Warp ends / inch	28.0 epi, +-2	
	Fill, picks / inch	31.0 ppi, +-2	
Top Face Selvage	Warp ends / inch	4 layers each 14.0 epi, +-2	
	Fill, picks / inch	3 layers each 28.0 ppi, +-2	
Fabric Areal Weigh		29 +- 4% (oz/sq. yard)	
Panel Areal weight	(including insulation)	100 + 15% (oz/sq. yard)	
Fabric Thickness (in.)	Top Face	0.034	
	Bottom Face	0.010	
	Rib Fabric	0.010	
	Selvage Edge	0.024	
Flute Height (in.)		0.986	
Panel Width (in.)		24.00	
Selvage Width (in.)	(top + bottom face)	2.00	

4.1.7 Fabrication / Test Equipment

The loom and creel setup at the weaver. Details might be added.

4.1.8 Schedule

The statements in bold are cooperative agreement milestones. The rest of the statements are Rockwell-set goals.

Demonstration of initial samples of Nicalon based TABI	8/30/94
Preliminary description of three weave configuration	8/30/94
Define final 3 strongest weave for Tyranno TABI	10/15/94

Produce additional Nicalon TABI for evaluation	10/15/94
Initiate first strong weave Tyranno TABI	12/23/94
Initiate second strong weave Tyranno TABI	2/15/95
Initiate third strong weave Tyranno TABI	4/30/94
Initiate production of 60 sq. ft. of strongest weave Tyranno TABI	7/15/95
Development of strongest weave Nextel 440 TABI	11/30/95
Produce TABI with metallic thread	4/30/96

4.2 Insulation Material Development

4.2.1 Introduction

This task includes evaluation of batting insulation material options (the candidate materials now are Nextel 440 and Saffil), development of cutting techniques on insulation materials and batting insertion techniques into the TABI woven structure, development of a process adaptable to large-scale production, and demonstration of techniques on 100 sq. ft. of woven TABI fabric structures.

4.2.2 Applicable Documents

Same as in Section 4.1.

4.2.3 Requirements

After the batting is inserted, the TABI composite (fluted core fabric structure plus the batting material) should have smooth OML and IML surfaces, and an uniform distribution of batting material to fully fill the TABI fluted core structure after heat clean. The requirement for the batting materials is to spring back after the binder is removed to fill 0.5" flute height for the first Nicalon TABI, and to fill 1" flute height for the remaining articles. The desired density of the batting material is 6 pounds per cubic foot (pcf) after the organic binder is burned off. Tests to be performed on the TABI composites are described in the later section (4.5).

4.2.4 Fabrication / Test Article Description

At least 100 sq. ft. of stuffed TABI, including Nicalon, Tyranno, Nextel 440 and TABI with metallic yarn in OML surface will be fabricated. Half of each kind of TABI will be stuffed with Nextel 440 batting (supplied by 3M) and half with Saffil (supplied by Zircar), unless one material was proven to perform unsatisfactory at the early developmental stage.

4.2.5 Fabrication Development / Test Procedure

4.2.5.1 *Obtain Batting Materials*

- Supplier rigidized Saffil - Zircar Products
- Supplier rigidized Nextel 440 - 3M
- Rockwell rigidized Nextel 440
- Rockwell rigidized Saffil

4.2.5.2 *Combining Layers / Rigidizing / Compression Methods*

- Binder: acrylic Carboset (B. F. Goodrich Co.) diluted with deionized water at ratios 1:2, 1:4, 1:5, 1:6 or 1:8 - saturate or spray
- Combine layers "comb" method, followed by press and binder
- Fabricate racks/containers/spacers
- Compression with Pneumatic press to spacer height for 2 hours
- Dry in oven at 200°F for ~2.5 hours

- Record recovered height

4.2.5.3 Experiment with Cutters

- Table saw
- Pneumatic hand held cutter
- Ultrasonic knife
- Regular knife
- Diamond tipped circular blade
- Wire saws
- Knife blade

4.2.5.4 Fabricate Tools for Cutting Desired Angles (if necessary)

- 60° for unrigidized batting
- Calculated angles for rigidized batting

4.2.5.5 Developing Tool for insertion

- Fabricate >24" long mandrels (tapered head) to be attached to the front of triangular batting for ease of insertion
- Triangular polyester / Mylar envelopes/ Scotch tape for maintaining shape and easier insertion, or
- 4 ml thick polyester or Mylar which can be formed into and maintain the triangular shape to wrap around cut batting and can be removed after insertion
- Fabricate tapered hollow nylon mandrel (For inserting batting without damaging TABI fabrics) to be attached to front of Mylar wrapped batting

4.2.5.6 Heat clean

- In air-circulated oven at 850°F for 4 hours to burn off binder, yarn lubricants, sizing and servings

4.2.6 Schedule

The insertion techniques will be fully developed by 10/15/94. The remaining effort of this subtask is to perform batting insertion for the eight TABI articles to be delivered by the weaver.

The statements in bold are cooperative agreement milestones. The rest of the statements are Rockwell-set goals.

Demonstrate TABI insulation insertion process	10/15/94
Insert batting into the first 0.5" Nicalon TABI	10/15/94
Insert batting into the second 1" Nicalon TABI	11/27/94
Insert batting into first weave of Tyranno TABI	2/15/95
Insert batting into second weave of Tyranno TABI	4/30/95
Insert batting into third weave of Tyranno TABI	6/30/95
Insert batting into strongest weave Tyranno TABI	8/31/95
Insert batting into Nextel 440 TABI	12/15/95
Insert batting into TABI with metallic yarn (assuming brazing happens after stuffing)	3/15/94

4.3 Composite Development

4.3.1 Introduction

Stuffed TABI composite as the result of the previous two subtasks will be heat cleaned, and the outer surface smoothness, uniformity, weight and compression characteristics will be evaluated in this subtask.

4.3.2 Applicable Documents

Same as in 4.1.

- ASTM-D-1372 Testing Package Cushioning Materials

4.3.3 Detailed Requirements

Uniform batting distribution which fully fills up the TABI fluted core structure with no air pockets as heat paths after heat clean, smooth TABI composite OML and IML surfaces, achieving desired final density and weight of the stuffed TABI composite are requirements of this subtask.

4.3.4 Fabrication / Test Article Description

The TABI composites will be the result of the previous two subtasks.

4.3.5 Test Procedure

4.3.5.1 *Heat clean*

850°F for 4 hours in an air-circulated oven to burn off binder, yarn lubricants, sizing and servings.

4.3.5.2 *Smoothness / density / weight /uniformity*

The smoothness and uniformity of the TABI composite will be visually inspected and measured by thickness gauges after heat clean..

4.3.5.3 *compression: strength / recovery*

This test will be conducted on the selected strongest weave Tyranno TABI.

4.3.5.3.1 **Specimens Description**

Fabricate six specimens 6" x 6" strongest weave Tyranno TABI, three with Saffil batting and three with Nextel 440 batting. Process and bond to 8" x 8" x 1/2" aluminum plates per MA0606-317. Heat clean and waterproofed with Z6070.

4.3.5.3.2 **Test Procedures**

Set up in the MTS test machine and perform test per ASTM-D-1372 (Testing Package Cushioning Materials). Record drift and set .

The original thickness will be established on each specimen under a load of 0.025 psi. The specimens are then cycled 0.025 to 25 psi for 100 cycles, making the hysteresis graph recording for the first, 25th, 50th, 75th, and the 100th cycle. The specimen thickness will also be measured after each of the aforementioned cycles under 0.025 psi and recorded as compressed thickness. After the compression cycling test is completed, the specimens will be allowed to recover unrestricted for 24 hours. At the end of the recovery period each specimen is loaded to 0.025 psi and remeasured for recovered thickness. This test will be repeated after a TBD amount of time.

4.3.6 Schedule

The schedule of this subtask involves heat cleaning, evaluation of smoothness, uniformity and measurement of density of the TABI composites. Compression test will be performed on the strongest weave of Tyranno TABI.

The statements in bold are cooperative agreement milestones. The rest of the statements are Rockwell-set goals.

Heat clean (H/C), smoothness, density, uniformity of 1st 0.5" Nicalon TABI	10/15/94
H/C, smoothness, density, uniformity of 2nd 1" Nicalon TABI	11/27/94
H/C, smoothness, density, uniformity of 1st weave Tyranno TABI	2/15/95
H/C, smoothness, density, uniformity of 2nd weave Tyranno TABI	4/30/95
H/C, smoothness, density, uniformity of 3rd weave Tyranno TABI	6/30/95
H/C, smoothness, density, uniformity and compression test of strongest weave Tyranno TABI	8/31/95
H/C, smoothness, density, uniformity of Nextel 440 TABI	12/15/95
H/C, smoothness, density, uniformity of TABI with metallic yarn	3/15/96

4.4 Surface Architecture

4.4.1 Introduction

This subtask is a joint effort between Rockwell and NASA Ames to attach metallic foil to the OML surface of TABI composites, it is also referred to as DuraTABI. NASA Ames will develop and provide concepts and techniques of metallic foil attachment to TABI. Rockwell will perform application of metallic foil attachment techniques to TABI.

4.4.2 Applicable Documents

Letter from T. Khaled (Rockwell) to D. Kourtides (ARC) discussing brazing options and limitations, Apr. 1994.

4.4.3 Detailed Requirements

TBD

4.4.4 Test Article Description

TBD

4.4.5 Test Procedure

- Wind tunnel and arc jet tests will be performed to examine the performance of DuraTABI concept. More tests could be added depending on the results. Details of the tests are described in Section 4.5.
- Development of means for Non-destructive Testing (NDT) to inspect the adequacy of braze joints.
- Metallographic evaluation of braze joints.

4.4.6 Schedule

The statements in bold are cooperative agreement milestones. The rest of the statements are Rockwell-set goals.

Metallic surface TABI development

4/30/96

4.5 Finished Composite Evaluation

4.5.1 Introduction

TABI composite blankets will be evaluated for surface durability, thermal and physical properties, venting and corrosion characteristics (for DuraTABl) in this subtask. The tests for evaluation in this subtask include plasma arc, wind tunnel, debris impact, rain erosion, vibroacoustics, radiant exposure, venting, and air impingement. The thermal and physical properties to be determined include emittance, absorptance, specific heat, their changes after thermal exposures, thermal conductivity and surface catalysity. The corrosion resistant of the DuraTABl metallic foil will be determined by the salt fog test.

4.5.2 Applicable Documents

To be specified in each of the tests listed below or in the DTP's in the Appendix section.

4.5.3 Detailed Requirements

To be specified in each of the tests listed below or in the DTP's in the Appendix section.

4.5.4 Detailed Test Article/Test Specimen Description

To be specified in each of the tests listed below or in the DTP's in the Appendix section.

4.5.5 Test Procedure

This evaluation subtask is divided into five phases. The first phase is to demonstrate that the Nicalon TABI is reestablished. Tests will include arc jet, guarded hot plate, mini wind tunnel, vibroacoustics and any tests called out in the Ames specification. Test specimens will be 0.5 Nicalon, one set with Saffil batting, and the other set with Nextel 440 batting.

The second phase of this subtask is to select the strongest weave among the three different Tyranno weaves. Tests will include mini wind tunnel, air impingement (for screening purpose), and arc jet test to determine the most durable, strongest weave. The test specimens will be six sets, two with each weave configuration, stuffed with Saffil batting in one set and Nextel 440 batting in the other.

The third phase is to evaluate the selected strongest weave Tyranno TABI. This is the phase of the subtask that involves most of the tests. They include plasma arc, wind tunnel, debris impact test, rain erosion, vibroacoustics, radiant exposure, and air impingement, measurements for emittance, absorptance, specific heat, the change of properties after thermal exposures, guarded hot plate for thermal conductivity, plasma arc for catalysity, and compression test. The test specimens will be the selected strongest weave Tyranno with two types of batting, Saffil and Nextel 440.

The fourth phase is the evaluation of Nextel 440 TABI and the fifth phase is the

evaluation of TABI with metallic foil attached (DuraTABI). The tests for both of these phases are TBD depending on the results of the strongest weave Tyranno TABI.

The tests mentioned in the earlier paragraphs are listed below. Details such as the specimen sizes, configurations, test parameters will be added.

4.5.5.1 Plasma arc, 20MW and 60 MW, (DTP 6451-810, see Appendix A).

This test will be utilized several times throughout to test different materials and different weave configurations for thermal properties and surface catalysity. In the first phase, 0.5" Nicalon TABI blanket will be tested by plasma arc to demonstrate that the TABI is reestablished (12/94). In the second phase, this test is utilized to select the strongest weave of Tyranno TABI (6/30/95). In the third, plasma arc is used to evaluate the strongest weave Tyranno after it is selected (8/31/94) for thermal properties as well as catalysity. Nextel 440 (12/95) and TABI with metallic thread and foil (5/30/95) might be evaluated later.

4.5.5.2 Wind tunnel, (DTP 6451-811, see Appendix B).

The schedule of the mini wind tunnel will be the same as that of plasma arc.

4.5.5.3 Debris impact, (DTP 6451-812, see Appendix C).

This test is utilized to evaluate the strongest weave Tyranno TABI (phase 3).

4.5.5.4 Rain impact, (DTP 6451-813, see Appendix D).

This test is utilized to evaluate the strongest weave Tyranno TABI (phase 3).

4.5.5.5 Vibroacoustics, (DTP 6451-817, see Appendix H).

This test is utilized in evaluating the first Nicalon TABI (phase 1) and the strongest weave Tyranno TABI (phase 3).

4.5.5.6 Radiant exposure, (DTP 6451-819, see Appendix J).

This test is utilized to evaluate the strongest weave Tyranno TABI (phase 3). Other properties such as emittance, absorptance, and durability (by air impingement) will be measured before and after exposures to certain number cycles of radiant heat environment.

4.5.5.7 Venting, (DTP 6451-820, see Appendix K).

This test is utilized to evaluate the strongest weave Tyranno TABI (phase 3).

4.5.5.8 Air impingement, (DTP 6451-822, Appendix L).

This test is utilized to select and evaluate the strongest weave Tyranno TABI (phase 2 and 3). The test coupons will be preconditioned (temperature, time, pressure and environment) as close as possible to the predicated flight environment prior to testing. The preconditioning could be performed at either of the radiant heating facility at NASA Ames or Rockwell.

4.5.5.9 Emittance ASTM E 408, Method A

4.5.5.9.1 Instrument

Gier-Dunkle, DB100 Infrared Reflectometer

4.5.5.9.2 Test Procedures

1. Perform normal emittance testing at room temperature.
2. The test equipment shall be calibrated with a certified standard supplied by Gier-Dunkle.
3. The emittance wavelength shall be detected through a potassium bromide window. The wavelength range is 5 - 25 microns.

Strongest weave Tyranno with Saffil and Nextel 440 will be measured for emittance before any radiant exposure, after 5 cycles of radiant exposure, and after 10 cycles of radiant exposure.

4.5.5.10 Absorptance ASTM E 490 - 73a

4.5.5.9.1 Instrument

Beckman, DK-2A UV-VIS-NIR Spectrophotometer

4.5.5.9.2 Test Procedures

1. Perform solar absorptance testing using a dual beam, ratio recording spectrophotometer with the beam light incident at 5 degrees from normal. The reflected light is scattered into a 6 inch diameter integrating sphere and detected by either a lead sulfide cell or a photomultiplier tube.
2. Record reflectance data as a percentage of a working standard's reflectance. Calibrate working standard against an NBS specular standard.
3. Record data from 280 to 2500 nanometers.
4. Compute Solar absorptance (Alpha) based on 25 equal energy intervals centered on wavelengths from 215 nanometers to 2600 nanometers. These wavelengths are computed from tables of spectra in NAS-SP-8005 and ASTM E 490.

Strongest weave Tyranno with Saffil and Nextel 440 will be measured for absorptance before any radiant exposure, after 5 cycles of radiant exposure, and after 10 cycles of radiant exposure.

4.5.5.11 Specific Heat ASTM C 351

This test is utilized to evaluate the strongest weave Tyranno TABI (phase 3). Details will be added.

4.5.5.12 Salt Fog Test ASTM E 117

The metallic foil (material to be determined by Ames) to be attached to the OML surface to TABI will be evaluated by Salt Fog test for corrosion resistance.

4.5.5.13 Guarded Hot Plate ASTM C 177

The first piece of Nicalon TABI will be tested per this to determine the thermal conductivity. This test may be subcontracted to an outside lab, FMI. The data obtained will be compared with old AFRSI results and TABI from previous program. Specimens will be stuffed with Saffil and Nextel 440 batting. (Dec. 94)

4.5.6 Schedule

The statements in bold are cooperative agreement milestones. The rest of the statements are Rockwell-set goals.

Perform tests on Nicalon TABI to demonstrate specification conformance	12/23/94
Selection of strongest weave for additional TABI evaluation	6/30/95
Evaluation testing to strongest weave TABI initiated	8/31/95
Evaluation of Nextel 440 TABI, tests are TBD	12/15/95
Evaluation of DuraTABI, tests are TBD.	5/30/96

4.6 Composite Processing

4.6.1 Introduction

Task include demonstration and/or evaluation of techniques for edge closeouts, forming, installation, penetrations, stacking and treatment of metallic skin joints.

4.6.2 Applicable Documents

- MA0105-346, "Fabrication of Tailored Advanced Blanket Insulation (TABl) Components, Dave Thomann
- LTR 14620-4220, "OEX Tailored Advanced Blanket Insulation (TABl) Material Characterization Tests G.R. Toombs, Feb. 1988
- LTR 4687-2012, "Tailored Advanced Blanket Insulation Folding Concepts", D.G. Thomann, Sep. 1986

4.6.3 Detailed Requirements

TBD

4.6.4 Detailed Test Article/Test Specimen Description

TBD

4.6.5 Fabrication Development / Test Procedure

The procedures for edge closeouts, forming to contours, installation, penetrations, bonding and effects on properties (such as the structure and foam) of the TABl blankets will be developed by using Rockwell processing specification for AFRSI, MPP605M315M01, Rev. F "Fabrication of Blanket Insulation Detail Parts", as a guideline. The details of the modifications will be added. The results of the developed processing procedures will be evaluated by visual inspection. The bonding procedure will be evaluated by the peel test as described below.

4.6.5.1 **Peel Test** ASTM D 903

4.6.5.1.1 **Test Procedures**

1. Bond a 6" x 9" TABl test specimen to an aluminum test panel per MA0606-317.
2. Verify "Shore A" to be a minimum of 50 for RTV adhesive.
3. Cut bonded specimen into 4 (1"wide strips).
4. Attach test specimen to Instron test machine and test at 90 to the panel substrate with a speed of 12"/minute, within 1.5 inches from the end of the test specimen.

4.6.5.2 *metallic skin joints and stacking*

TBD

4.6.6 Schedule

The statements in bold are cooperative agreement milestones. The rest of the statements are Rockwell-set goals.

Initiate development of processing procedures on selected TABI	2/29/96
Preliminary TABI installation procedures	4/30/96
Initiate development of process procedures on DuraTABl	5.31/96
Prepare drafts of TABI processing specification	6/30/96

**2.4.2.2. EVALUATE ADVANCED FLEXIBLE TPS
THAT INCORPORATE MLI FOR SSTO
VEHICLES
Test Plan 2.2 thru 2.6**

Advanced Structures and TPS Technologies NRA8-12

Co-operative Agreement NCC2-9003

Lightweight Durable Thermal Protection System TA-3

TASK LEADER: GAY WILSON

DETAIL TEST PLAN - JULY 25, 1994

DRAFT

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SECTION: 1

1.0 OBJECTIVE:

The objective of this test program is to develop a lightweight durable Composite Flexible Blanket Insulation (CFBI) to a technology readiness level of 6, and to incorporate this composite technology into Tailorable Advanced Blanket Insulation (TABI). The program objective is to develop a relatively maintenance free thermal protection system which will reduce operations costs.

2.0 BACKGROUND:

This document defines the test plan for evaluating the Advanced Flexible TPS with Multi-Layer Insulation (MLI) described in task 2 of TA-3 "Lightweight Durable Thermal Protection System" to SSTO flight conditions and environments. **Section 1.** of this document details the overall requirements for task 2, **Section 2**, defines the sub-tasks as identified in paragraph 2.4.2.2. of the Statement of Work, and **Section 3**, the Appendix, presents detailed test procedures and requirements.

The flexible insulation to be developed and optimized in this test program is a Composite Flexible Blanket Insulation (CFBI) developed at the NASA Ames Research Center. The CFBI is multilayer insulation consisting of ceramic fabrics, insulation, and reflective foils that are separated by ceramic scrim cloths and is of similar construction to the AFRSI used in the Shuttle Thermal Protection System except for the reflective foils and scrim cloths. CFBI insulation is intended for use in the space vacuum when gas conductivity between the foils is negligible and the overall effective thermal conductivity is very small. The foils are used to reflect any radiative component in the SSTO heating environment. This appropriately designed CFBI insulation could operate efficiently within the heating and pressure environment of SSTO, providing a weight savings compared to other types of insulation. This task will develop the blanket radiation shield composite with an emphasis on operations issues as well as performance. Integration of multi layer insulation (MLI) into the TABI flexible blanket is a task goal. All materials will be selected and evaluated with respect to mission environment effects on optical properties. Performance will be evaluated, installation process variables will be investigated. Overall thermal performance will be demonstrated using arc-jet for high temperature testing and liquid nitrogen boil-off for cryogenic testing. Demonstration of mission performance will then be accomplished including such tests as radiant heat, arc jet, vibro-acoustic and temperature/pressure cycling.

3.0 APPLICABLE DOCUMENTS:

Co-operative Agreement:

NCC2 - 9003 "Lightweight Durable Thermal Protection System"

4.0 GENERAL REQUIREMENTS:

4.1 Documentation

- 1. Detailed Test Procedure (DTP)** All testing will be conducted in accordance with these test procedures.
- 2. Laboratory Notebook** A Laboratory Notebook will be maintained by the Rockwell Responsible Test Engineer (RTE) depicting a complete test history. Test article configuration, instrumentation, test anomalies and all other pertinent data and information will be recorded.
- 3. Test Report** The test agency will issue a Laboratory Test Report (LTR). The test report will depict the complete test program, instrumentation, test procedures and results, test setup, photographs, test data and any other pertinent information.

4.2 Test Facility

Test equipment and facilities will be utilized at both government and industry facilities. Appropriate facilities are selected to best simulate the identified SSTO flight environments. Test facilities which will be used are listed below.

- NASA-Ames arcjet facilities, 60 and 20 MW facilities
- NASA-Ames light gas gun
- Rockwell cryogenic tank facility for ice/frost testing
- Rockwell rain/wind facility
- Rockwell salt spray environment facility
- Rockwell vibroacoustic facility
- Rockwell radiant heat facility

Schedules and test requirements are defined in **Section 2 Sub Tasks Description**, of this document. Detailed test procedures are located in the **Appendix, Section 3**.

4.3 Instrumentation:

All measurement instrumentation shall be calibrated and have a decal showing a valid calibration date. A list of all test instrumentation will be maintained in a Laboratory Notebook.

4.4 Test Conduct:

The test program will be conducted under the direction of the task leader or a designated representative.

SECTION: 2

SUB TASKS DESCRIPTIONS

2.2. RADIATION SHIELD DEVELOPMENT:

2.2.1. INTRODUCTION:

MLI (radiation shield) development - This task will include the selection and definition of radiation shield materials and development of assembly techniques for the package attachment to the adjacent blanket. Metallic foils and metalized organic films will be assessed for optical properties, and handling/assembly characteristics. Selection criteria will include the effect of critical mission environments (salt fog, humidity, waterproofing) on radiation shield optical properties.

2.2.2. OBJECTIVE:

Evaluate and define materials characterization as applicable to assembly processing and performance characteristics. Candidate materials will be assessed through the test methods defined below to evaluate handling/processing and typical environmental effects on the performance of the radiation shield materials.

2.2.3. APPLICABLE DOCUMENTS:

ASTM B 117	Salt Spray (Fog) Testing
ASTM E 408	Total Normal Emittance of Surface Using Inspection Meter Techniques
ASTM E 490	Solar Constant and Air Mass Zero Solar Spectral Irradiance Tables
MIL-STD - 810 D	Environmental Tests Methods and Engineering Guidelines
ML0311-0010	Fabrication of Multilayer Insulation Blankets

2.2.4. REQUIREMENTS:

1. Baseline assembly of the radiation shield package shall comply with ML0311-0010. Deviations will be documented as applicable to the SSTO program.

2.2.5. TEST ARTICLE DESCRIPTION:

1. Component radiation shield materials for the CFBI

- | | |
|------------------|--|
| Reflective foils | 1) Aluminized (oneside) Kapton film 0.500" thick |
| | 2) Titanium foil Beta 21S, 0.0005 -+0.0002 " thick |
| Scrim Spacers | 1) Nomex scrim |
| | 2) AB312 Ceramic cloth, 600 Denier, lino weave 101 gr/sq-meter |
| Thread | 1) Nextel 440, 700 denier 2 ply twist/inch wrapped at 2 ends with a carrier yarn of 55 denier rayon with 17, wraps/inch with an overwrap of rayon or dacron. |
| | 2) Nextel 440 - same as above except with PTFE sizing |

2. Radiation shield component package:

- 1) Aluminized Kapton film (perforated) - 10 plies with Dacron spacers
- 2) Aluminized Kapton film (perforated), crinkled or embossed -10 plies
- 3) Titanium foil , 0.0005" thick with AB312 ceramic cloth used as spacers - 5 plies

Note: Test specimen size to be determined

2.2.6. TEST PROCEDURES:

1. Effects of Waterproofing

**MIL-STD 801 D,
Method 507.1**

This test will evaluate the effects of the post flight waterproofing chemical Dimethylethoxysilane (DMES) on the radiation shield materials. The test specimens will be exposed to vapor and liquid DMES. Metallurgical analysis ie, scanning electron microscope (SEM) will be used to assess the effects of DMES on the Titanium foil. The aluminized Kapton organic film will be evaluated by infrared spectrophotometry to determine the effects, if any, on the Corrosion Resistant Coating (CRC). The aluminized surface will be examined metallurgically. The aluminized Kapton film will also be evaluated for delamination by the "Scotch" tape test.

- 1.1. Prepare test specimens for vapor phase exposure as follows:
Place test specimens into a closed chamber with 100% DMES vapor for 7 days minimum. Check specimens (per. 1.3) periodically after 8hrs, 24hrs, 48hrs, and 168hrs.

- 1.2. To prepare test specimens for liquid phase exposure:
Immerse test specimens into liquid DMES for 2 minutes, 30 minutes and 60 minutes. Allow test specimens to air dry at room temperature after immersion. Evaluate per 1.3

- 1.3. Perform metallurgical analysis on the titanium foil to check for evidence of corrosion. Perform infrared spectrophotometric analysis or equivalent on the aluminized Kapton, and check for evidence of degradation. Check for delamination by the "Scotch" tape test.

2. Salt Fog

Salt Fog - ASTM B 117

3. Humidity

MIL-STD-810 D, Method 507.1, Procedure 1

Each radiation shield package will be placed into a humidity chamber and submitted to a minimum of 10 humidity cycles. Each cycle is 24 Hrs. beginning at room temperature and increasing to 150°F and back to room temperature while maintaining R.H. in excess of 95%.

4. Optical Properties

This test is designed to evaluate the effects of typical operations vehicle environments on the optical properties of the radiation shield package. The test specimens will have been exposed to the post flight waterproofing chemical, DMES, and salt fog and humidity representative of launch pad conditions. The test specimens will have been prepared in tests 1. through 3. of this sub task. A control specimen will be used to establish a point of reference.

A. Emittance

ASTM E 408, Method A

Gier-Dunkle, DB100 infrared reflectometer

1. Perform normal emittance testing at room temperature.
2. The test equipment shall be calibrated with a certified standard supplied by Gier-Dunkle.
3. The emittance wavelength shall be detected through a potassium bromide window. The wavelength range is 5-25 microns.

B. Absorptivity Testing

ASTM E 490 -73a

Beckman, DK-2A UV-VIS-NIR Spectrophotometer

1. Perform solar absorptance testing using a dual beam, ratio recording spectrophotometer with the beam light incident at 5 degrees from normal. The reflected light is scattered into a 6 inch diameter integrating sphere and detected by either a lead sulfide cell or a photomultiplier tube.
2. Record reflectance data as a percentage of a working standard's reflectance. Calibrate working standard against an NBS specular standard.
3. Record data from 280 to 2500 nanometers.

4. Compute Solar absorptance (Alpha) based on 25 equal energy intervals centered on wavelengths from 215 nanometers to 2600 nanometers. These wavelengths are computed from spectra tables in ASTM E 490.

2.2.7. SAMPLE DATA SHEETS:

Test #1 Effects of Waterproofing

100% DMES Vapor

Specimen I.D. No.	8hrs.	24hrs.	48hrs.	168hrs.
xxx				
xxx				
Evidence of Delamination				

Liquid DMES

Specimen I.D. No	Exposure Time	2 min.	30 min.	60 min.
xxx				
Evidence of Delamination				

Test # 2 Salt Fog

Test # 3 Humidity

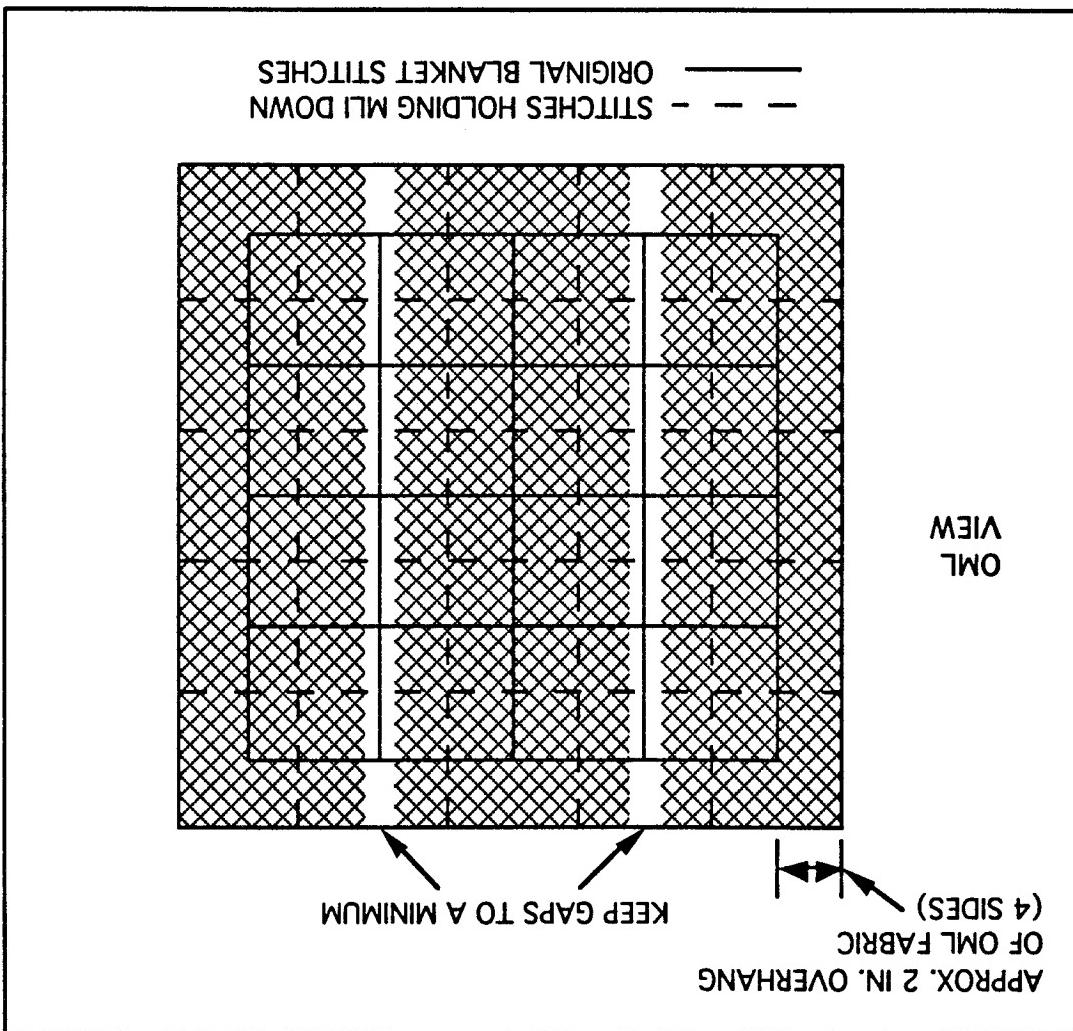
95% R.H., RT to 150°F, 24 hr. cycle time

Sample I. D. No.	No of cycles	1	2	3	4	5	6	7	8	9	10
xxx											
xxx											

Test # 4 Optical Properties

Sample I. D. No.	α	ϵ	$\alpha_s \epsilon / \text{th}$
xxx			
xxx			
Ave. Values			

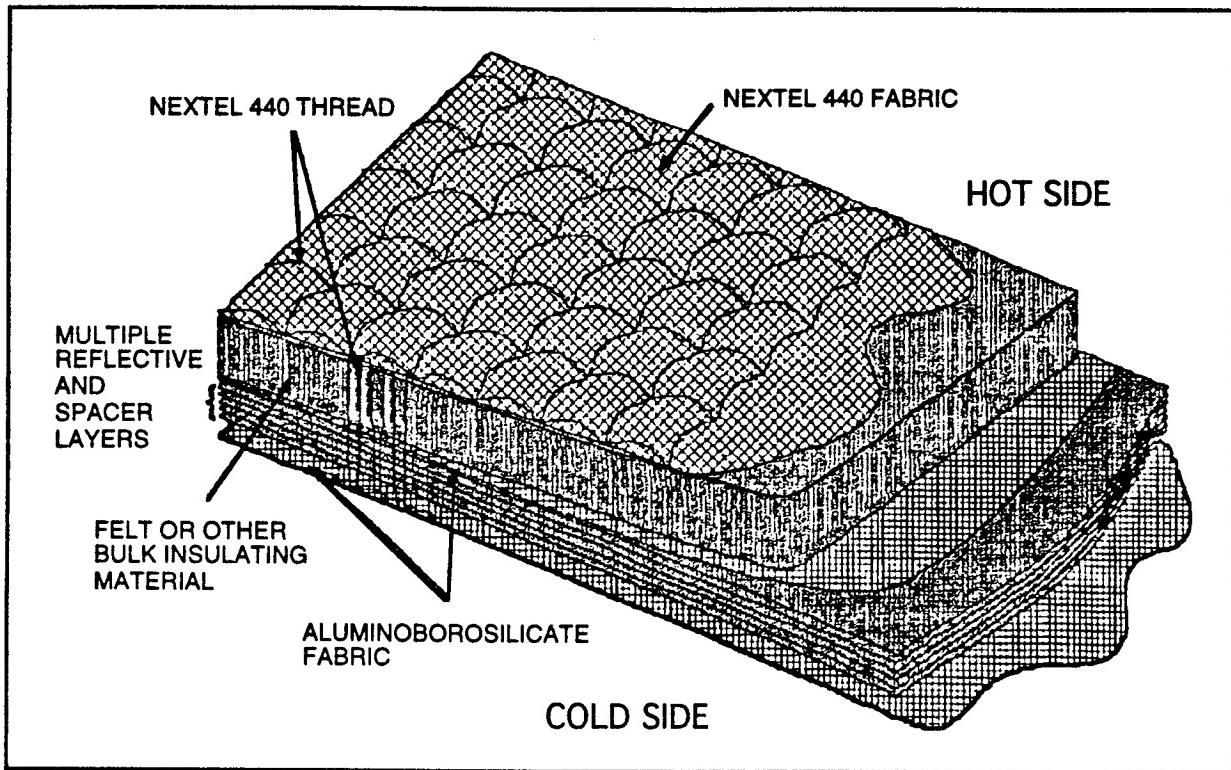
1. CFB1 STITCH Pattern



2.2.9. SKETCHES/SCHEMATICS:

1. Closed chamber Minimum of 4 liter capacity Capable of maintaining a minimum of 95% R.H. and 150°F
2. Humidity chamber Gier-Dunkle, DB100 infrared Beckman, DK-2A UV-VIS-NIR
3. Reflectometer
4. Spectrophotometer

2.2.8. EQUIPMENT:



2. CFBI Configuration

2.2.10. SCHEDULE FOR SUB TASK:

***Definition/Selection of radiation shield
MLI package and a purchase order prepared**

August 30, 1994

**Begin test specimen preparation/ for exposure to
waterproofing, salt fog & humidity environments**

September 30, 1994

***Testing of MLI optical properties initiated**

October 15, 1994

***Measure optical properties after
environmental exposure**

April 30, 1995

*** Denotes milestones**

2.3 DEVELOPMENT/CHARACTERIZATION OF BLANKET RADIATION SHIELD COMPOSITE

2.3.1. INTRODUCTION:

The development of process/assembly procedures for the blanket-MLI composite will include determining size limitations, edge close-outs, installation over contoured surfaces, weight and uniformity. The effect of process variables on performance will be determined by radiant heat, air impingement, venting, salt spray/arc jet (corrosion) and vibroacoustic tests. Initial development may be performed with CFBI but the ultimate goal is to combine the MLI package with advanced flexible TPS (TABl).

2.3.2. OBJECTIVES:

Develop an attachment process for MLI, which when installed onto flexible insulation will form an efficient high-temperature flexible blanket composite. Attachment techniques developed on CFBI will be applicable to TABl. Attachment/assembly processes will be evaluated in the Composite Flexible Blanket Insulation (CFBI) configuration by defining the blanket's performance limits when subjected to the following tests defined in 2.3.6..

2.3.3. APPLICABLE DOCUMENTS:

MA0606-317	RTV Adhesive Bonded Flexible Insulation
ML0311-0010	Fabrication of Multilayer Insulation Blankets
MB0135-012	Insulation, Thermal, Fibrous
MB0135-089	Fabric, Glass, High Temperature
MB0135-102	Thread, High Temperature Ceramic
MB0135-079	Aluminized Polyimide Film

2.3.4. REQUIREMENTS:

1. Baseline processing for CFBI test specimens will be per MA0606-317, except as noted.
2. Baseline processing for the radiation shield package will be per ML0311-0010, except as noted.

2.3.5. TEST ARTICLE DESCRIPTION:

Materials

1. Nextel 440 Fabric
Interlock weave, Pat # 5,277,959
(figure #4)
2. Q-Felt Insulation
6lbs/ ft.³ density
(MB0135-012, Ty I, Cl2)
3. AB312 Fabric
(MB0135-089)
4. Thread, Nextel 440, 700D/2ply
(MB0135-102, Ty II)
5. Aluminized Kapton film
One sided, 0.0002" thick
(MB0135-084 ,ty I, cl 1, grade A)

Suppliers

- Fabric Development
1217 Mill St.
Quakertown, Pa 18951
- Schuller Speciality Insulation, Div.
P.O. Box 5108
Denver, Colorado, 80217-5108
- J.P. Stevens & Co.
Slater, S. C.
- 3M Company
225-4N, 3M Center
St. Paul, Mn. 55144
- Sheldahl
801 N. Highway 3
P.O. Box 170
Northfield, Mn.55057

Sufficient blanket materials to produce a minimum of:
50 sq. ft of 1" thick standard CFBI

2.3.6. TEST PROCEDURES:

**1. Thermal Conductance Test
by Radiant Heat**

DTP 6451-819, Appendix

Objective:

Establish baseline thermal conductivity data by measuring structure backface temperature differential by comparing standard AFRSI with standard CFBI when exposed to a radiant heat test. Thermal data obtained from this test will be used for comparison/screening purposes when evaluating the performance characteristics of the radiation shield package. Orbiter reentry temperature and pressure profile will be used. NASA Ames will supply one each 8"x8" test specimen.

Test Method:

This test will assess the thermal performance characteristics of CFBI in a radiant heat environment. Each test specimen shall be exposed to three radiant mission profiles (baseline orbiter) with maximum surface temperatures of 800, 1100 and 1500°F. Figures 1 thru 3 in 2.3.9. define time, temperature and pressure requirements.

2. Salt Spray/Arc Jet

DTP 6451-810, Appendix A

3. Air Jet Impingement

DTP 6451-822, Appendix L

Purpose:

This test procedure will be used in this task as a screening method to evaluate how the blanket prototype performs in an aerodynamic environment. Attachment methods, such as stitching, edge close-out techniques, compression responses, and fabric stability can be quickly assessed prior to more extensive wind tunnel tests. Typically test specimen size is 4"x4" or less.

4. Venting

DTP 6451-820, Appendix K

Purpose:

The purpose of this test is to determine the venting behavior of the CFBI when subjected to a simulated ascent pressure profile.

Test Article Description:

The test article consists of CFBI 5"x5"x1' bonded with RTV 560 to an aluminum baseplate measuring 7"x7"X0.125". A venting hole positioned into the center of the test article penetrates through the CFBI to the bondline at the CFBI/baseplate interface. The hole diameter is 0.020 inches. On the back side of the aluminum plate a 0.125 inch diameter hole is drilled and a tube of equal diameter is inserted and secured with epoxy adhesive. This tube will be connected to the pressure side of the differential pressure transducer.

Test Method:

Venting tests will be conducted in a 18 inch minimum diameter bell jar. Capacitance-type transducers, used to measure absolute differential pressure are mounted outside of the bell jar and connected to the test article by approximately 4 1/2 feet of 0.25 inch OD copper tubing. The chamber pressure (P_{CH}) shall be monitored with a 0 to 25 psi absolute pressure transducer. The differential pressure inside the test article shall be monitored with a 0± 2.5 psid differential pressure transducer. The reference side of the differential transducer is connected to the chamber pressure line. Monitor and record the chamber pressure and test article differential pressure during simulated ascent with a Doric Model 220 data logger system or equivalent.

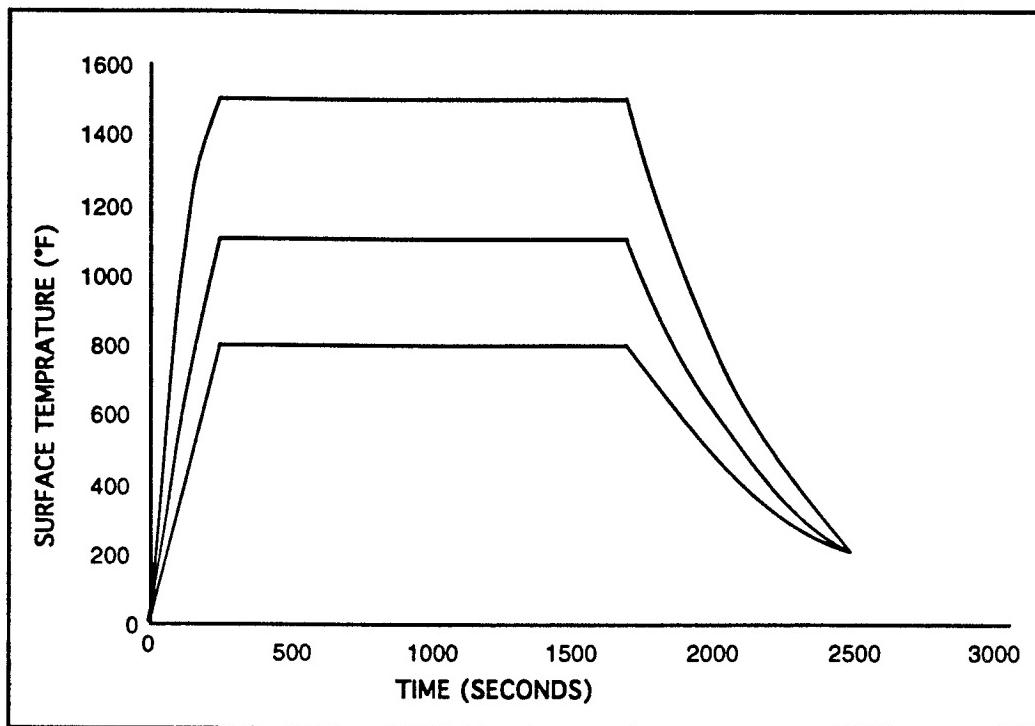
5. Vibro/Acoustic

DTP 6451-817, Appendix H

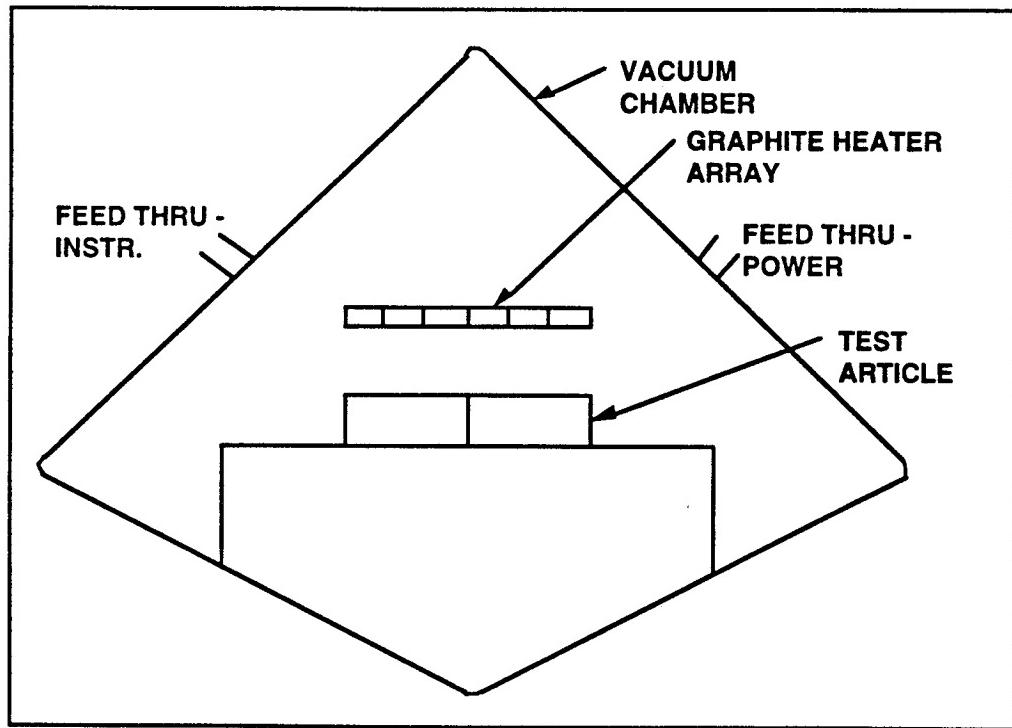
2.3.7. SAMPLE DATA SHEETS

2.3.8. EQUIPMENT:

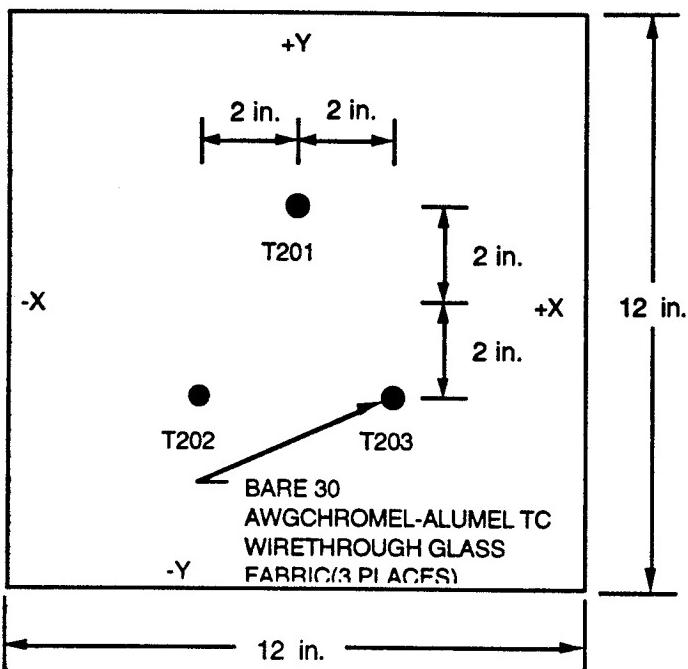
1. Radiant heat furnace - Capable of maintaining a minimum of 1500°F, with pumping capabilities to achieve/maintain chamber pressure of approximately 7×10^{-1} Torr
2. Sufficient controls to obtain relatively uniform surface temperatures.
3. Data Logger System, Doric Model 220, or equivalent.

2.3.9. SKETCHES/SCHEMATICS:

1. Radiant heat time and temperature parameters



2. Radiant Heat Chamber

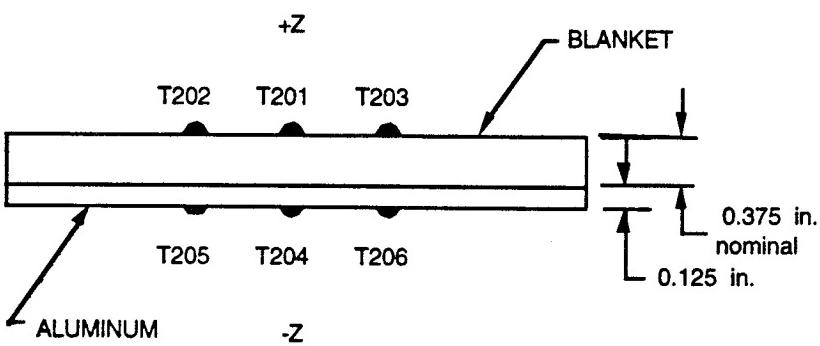


PANEL C12

T201	93.9Ω	T204	97.2Ω
T202	94.6	T205	96.2
T203	94.7	T206	97.2

PANEL C12A

T201	93.9Ω	T204	97.2Ω
T202	94.6	T205	96.2
T203	94.7	T206	97.2



3. Radiant heat thermocouple set-up

2.3.10. SCHEDULE FOR SUB TASKS:

- | | |
|---|--------------------------|
| *Preliminary plan for assembly of blanket/MLI package | November 15, 1994 |
| *Perform development of MLI assembly and fabricate insulation blanket components | December 23, 1994 |
| *Demonstrate attachment of MLI to blanket | December 23, 1994 |
| *Perform development of blanket/MLI assembly and edge close-out | February 15, 1995 |
| *Perform characterization tests on blanket/MLI composite specimens | April 30, 1995 |

***Denotes Milestones**

2.4. INSTALLATION OF BLANKET/MLI

2.4.1. INTRODUCTION:

Process installation development for the CFBI onto typical SSTO vehicle structures will include devising attachment techniques, controlling steps and gaps, and providing for structure transitions, interfaces and penetrations. Baseline AFRSI installation processing will be assessed for applicability to CFBI. Alternative installation methods, such as mechanical attachment with the use of Velcro will also be assessed. Performance evaluation will be by arcjet testing.

2.4.2. OBJECTIVE:

Define installation requirements for CFBI which comply to all SSTO structure conditions and determine the effect of installation variables on blanket performance.

2.4.3. APPLICABLE DOCUMENTS:

- | | |
|----------------|---|
| 1. ML0301-0034 | Flexible Insulation (FI) Installation - Orbiter Vehicle |
| 2. MA0606-317 | RTV Adhesive Bonded Flexible Insulation |
| 3. ASTM D 903 | Peel or Stripping Strength of Adhesive Bonds, Test for |

2.4.4. REQUIREMENTS:

1. Baseline processing for CFBI shall be in accordance with ML0301-0034. Deviations as required for the SSTO program will be documented.

2.4.5. TEST ARTICLE DESCRIPTION:

1. Peel test coupons 6" by 9", quantity as required
2. 10 instrumented 1" thick standard CFBI
3. Planform size to be determined

2.4.6. TEST PROCEDURES:

- | | |
|--------------|--------------------------|
| 1. Arc jet | DTP 6451-810, Appendix A |
| 2. Peel Test | ASTM D 903 |

The purpose of this is to quickly assess the effects of structure transitions and interfaces for bonded installations. This test will be used as a screening test and the test results compared to baseline AFRSI installations.

Specimen Preparation - Refer to Sketch #1. "Typical Peel Test Coupon"

1. Bond a six by nine inch CFBI test specimen to an aluminum test panel per MA0-606-317.
2. Verify Shore a minimum of "A" 50 for RTV adhesive

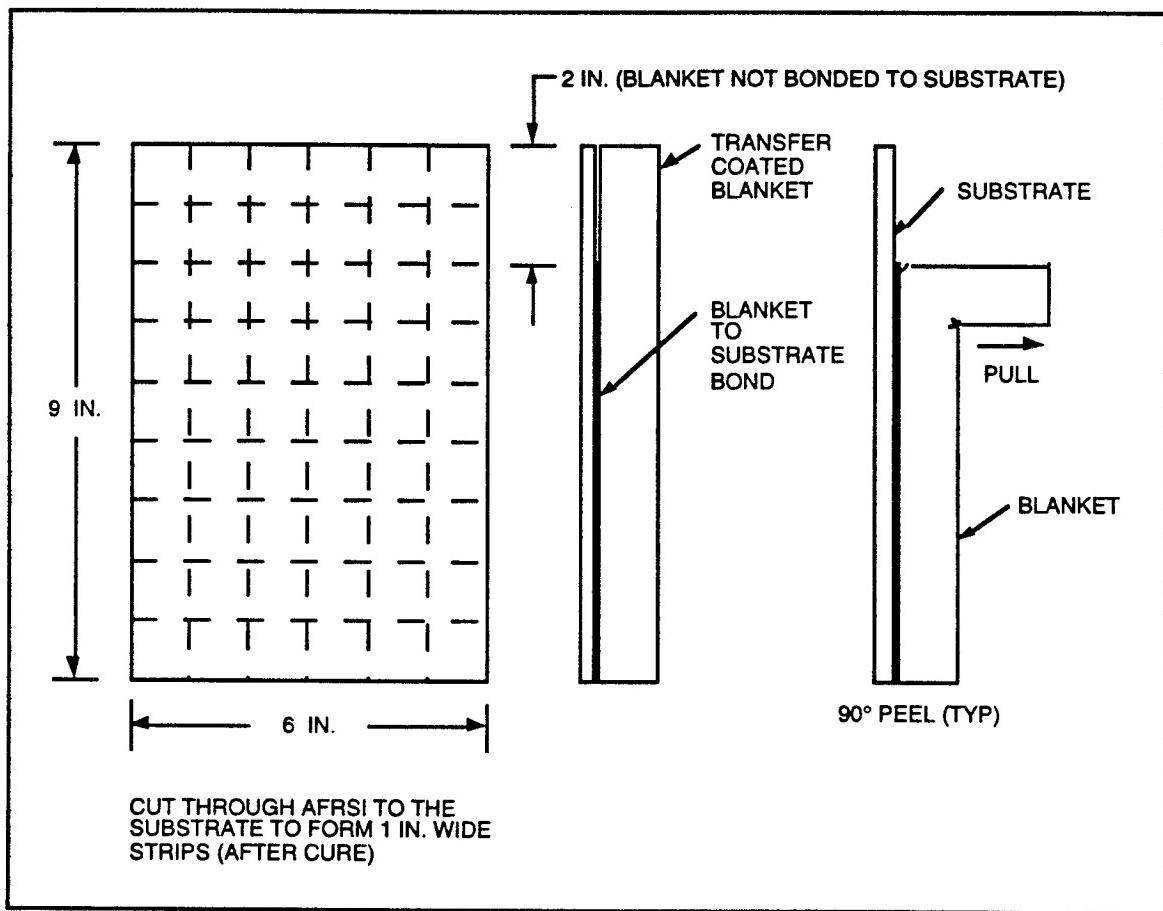
3. Cut bonded specimen into 4 (1 inch wide strips)
4. Attach test specimen to Instron test machine and test at 90° to the panel substrate with a speed of 12"/minute, within 1.5 inches from the end of the test specimen.

2.4.7. SAMPLE DATA SHEETS:

2.4.8. EQUIPMENT:

1. Instron Tensile Test Machine

2.4.9. SKETCHES/SCHMATICS:



1. Typical Peel Test Coupon

2.4.10. SCHEDULE FOR SUB TASK

***Evaluate methods of attaching blanket/MLI to structure**

April 30, 1995

***Evaluate blanket assembly installation variables (steps, gaps, transitions)**

January 1, 1996

***Develop techniques for penetrations in blanket/MLI assembly**

February 29, 1996

***Denotes Program Milestones**

2.5. OPTIMIZATION OF BLANKET/MLI

2.5.1. INTRODUCTION:

Thermal analyses will be performed to determine high temperature and cryogenic applications for the developed blanket. High temperature performance will be demonstrated through arc jet testing; cryogenic insulation enhancement will be evaluated by liquid nitrogen boil off test.

2.5.2. OBJECTIVE:

To obtain thermal characterization of the CFBI by creating a one dimensional heat transfer math model to emulate the generic variables such as density, thickness and surface conditions and to correlate this to data obtained from the experimental tests. This data to be used as design criteria for establishing CFBI thickness and gap sizing requirements. The AFRSI will be used for control purposes.

2.5.3. APPLICABLE DOCUMENTS:

2.5.4. REQUIREMENTS:

2.5.5. TEST ARTICLE DESCRIPTION:

2.5.6. TEST PROCEDURE:

- | | |
|-----------------|----------------------------|
| 1. Arc jet | DTP 6451 - 810, Appendix A |
| 2. Radiant Heat | DTP 6451 - 819, Appendix J |

2.5.7. SAMPLE DATA SHEETS:

2.5.8. EQUIPMENT:

2.5.9. SKETCHES/SCHEMATICS:

SCHEDULE FOR SUB TASKS:

- ***Thermal performance of blanket/MLI composite specimens initiated** **July 30, 1995**
 - ***Preliminary analysis of performance of blanket/MLI for high temperature and cryogenic applications accomplished** **August 31, 1995**
 - ***Cryogenic testing of blanket/MLI insulation on tank specimen initiated** **September 30, 1995**
 - ***Initiate aerothermal performance evaluation of blanket/MLI** **November 30, 1995**
- *Denotes Program Milestones

2.6. PERFORMANCE DEMONSTRATION

2.6.1. INTRODUCTION:

Mission performance testing under aerothermal, vibroacoustic, vibration/deflection, buffeting, cold soak and pressure profile conditions will be performed using individual or arrays of blankets. Test conditions will be as defined for an SSTO vehicle or can be those used for Orbiter TPS evaluation.

2.6.2. OBJECTIVE:

The objective of this task is to demonstrate the technology readiness level of the CFBI Thermal Protection System (TPS) by subjecting a system prototype to typical SSTO flight environments and conditions.

2.6.3. APPLICABLE DOCUMENTS:

2.6.4. REQUIREMENTS:

2.6.5. TEST ARTICLE DESCRIPTION:

2.6.6. TEST PROCEDURES:

- | | |
|--|--------------------------|
| 1. Arc jet | DTP 6451-810, Appendix A |
| 2. Wind Tunnel | DTP 6451-811, Appendix B |
| 3. Vibroacoustic (progressive wave) | DTP 6451-817, Appendix H |
| 4. Mechanical vibration (vibration/deflection) | DTP 6451-818, Appendix I |
| 5. Ascent pressure profile (orbit cold soak) | TBD |

2.6.7. SAMPLE DATA SHEETS:

2.6.8. EQUIPMENT:

2.6.9. SKETCHES/SCHMATICS:

2.6.10. SCHEDULES FOR SUB TASKS:

- | | |
|--|--------------------|
| *Extreme environmental thermal testing of blanket/MLI defined | August 31, 1995 |
| *Performance evaluation of blanket/MLI composite | January 1, 1996 |
| *Blanket/MLI properties and performance (aerothermal and wind tunnel after installation) | April 30, 1996 |
| *Test blanket/MLI assembly (vibroacoustic and vibration/deflection) | June 30, 1996 |
| *Blanket/MLI specimen cold soak and mission profile testing | July 30, 1996 |
| *Initiate preparation for final report | September 30, 1996 |

*Denotes program milestones

**ADVANCED STRUCTURES AND TPS
TECHNOLOGIES
NRA 8-12
TA-3 TASK 4**

TPS ATTACHMENT METHODS

TASK LEADER: DAN BELL

DETAILED TEST PLAN - DRAFT JULY 22, 1994

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1.0 OBJECTIVE

Several NASA studies have shown the need for a space transportation system design driven by operational criteria. The proposed development program is based on NASA and Rockwell's success with TPS materials on the Space Shuttle orbiter. Orbiter ceramic tile and blanket TPS has been very effective thermally, but improved durability and other enhancements can significantly increase mission flexibility and reduce operations costs.

All Task 4 testing will utilize the increased strength Alumina Enhanced Thermal Barrier (AETB) tile and where tile coating is required Tuffened Unipiece Fiberous Insulation (TUFI) an enhanced tuffness coating will be utilized.

Secondly, Task 4 of SSTO's (Single Stage To Orbit) TA-3 will meet these objectives by first reduction of weight through the use of "Direct Bond" advanced TPS tiles. This method of attaching tile to the structure will be tested to demonstrate the TPS systems effectiveness and to provide design allowables for use in structure fabrication.

Third, Task 4 is looking at new methods of attaching TPS to the structure. The use of specialty Velcro has been suggested for this purpose. Velcro would provide, reliable cost effective method for removal and replacement of tile and blankets. A suitable candidate will be subjected to physical and environmental testing to evaluate its effectiveness and durability.

Finally, the current tile system utilized on the Space Shuttle orbiter is very effective thermally, but it lacks the durability required by SSTO. Ceramic Matrix Composite (CMC) "Top Hat" cover combines the durability of a CMC with the thermal insulation of a tile. Several methods of attaching the CMC will be evaluated and the most favorable candidate will be subjected to physical and environmental testing.

2.0 BACKGROUND

Attaching TPS materials to vehicle structure or TPS components to each other is one of the most critical areas of the SSTO design and development. The two primary techniques for attaching TPS to a structure are adhesive bonding and mechanical attachment. There are advantages and disadvantages to each.

The additional weight, added complexity during original installation and operational maintenance of fasteners led Rockwell to concentrate on optimizing the adhesive bond.

Task 4 "TPS Attachment Methods" is separated into the four development Subtasks listed below.

- Subtask 4.1: AETB-12/AETB-8 Fabrication
- Subtask 4.2: Direct Bond Development
- Subtask 4.3: Velcro Attachment
- Subtask 4.4: Attachment of "Top Hat" Cover to TPS Tile

A brief introduction to each phase and the test articles developed from each follows.

2.1 "Subtask 1: AETB-12/AETB-8 Fabrication". This involves the fabrication of 12 lb/ft³ and 8 lb/ft³ Alumina Enhanced Thermal Barrier (AETB-12/ AETB-8) for use in the final three subtasks of Task 4. Current specimen requirements call for 157 coated and uncoated tiles ranging in size from 2-x-2-in coupons to 10-x-10-in tiles. All tiles requiring coating will be sprayed with Tuffened Unipiece Fiberous Insulation (TUFI).

2.2 "Subtask 2: Direct Bond Development". By direct bonding tile to a graphite bismalimide (Gr/BMI) structure significant weight savings and/or thermal performance can be realized. The elimination of the strain isolator pad (SIP) is made possible by the similar coefficient of thermal expansion in the tile and GR/BMI substrate. With the elimination of SIP, substrate deflections must be limited by design to prevent TPS loss and damage. All testing in this subtask of Task 4 is based on providing design allowables for this structure deflection.

Testing will include in-plane strain, substrate deflection, flatwise tension on single tile bonded to a graphite bismalimide substrate, deflection, vibroacoustics, and structure mismatch . Testing will be conducted at room temperature as well as various elevated temperatures.

2.3 "Subtask 3: Velcro Attachment". The use of specialty Velcro has been suggested for attaching TPS components to vehicle structure or foam. Velcro could provide benefits in joint reliability, component removal and weight.

Vendors will be surveyed to find suitable candidate types after which they will be evaluated to verify their durability to the harsh SSTO flight and

operational environments. Velcro strength/durability will be evaluated on new material and after several removals. If strength and environmental durability are adequate, method of attaching the Velcro to the tile, blankets and various substrates will be explored. On completion of the task a seven tile array will be fabricated and exposed to humidity, wind/rain, and cold.

2.4 "Subtask 4: Attachment of "Top Hat" Cover to TPS Tile". Ceramic tiles are very efficient and predictable TPS components, but they are easily damaged by debris and rain/cloud impacts. Flight/operational restrictions must be placed on a vehicle to protect the current tile systems from damage. One concept to limit or remove the need for such restrictions is to increase the "Tuffness" of the tile surface by attaching a ceramic matrix composite (CMC) to the tile surface. The attached CMC cover would increase the tile durability yet the system would remain an efficient insulator.

The CMC cover will be attached using adhesive and mechanical methods. Attachment will be conducted on AETB-12 and AETB-8 tile substrates, first on coupon-size specimens then to 6-x-6-in tiles fabricated for radiant and arc jet thermal tests. CMC cover specimens will then be attached to GR/BMI substrate and tested for performance under substrate deflection and vibroacoustic loading.

3.0 GENERAL REQUIREMENTS

3.1 Documentation

3.1.1 Detailed Test Procedure (DTP)

All testing will be conducted in accordance with this test procedure.

3.1.2 Laboratory Notebook

A Laboratory Notebook will be maintained by the Rockwell Responsible Test Engineer (RTE) depicting a complete test history. Test article configuration, instrumentation, test anomalies and all other pertinent data and information will be recorded.

3.1.3 Test Report

The test agency will issue a Laboratory Test Report (LTR). The test report will depict the complete test program, instrumentation, test procedures and results, test setup, photographs, test data and any other pertinent information.

3.2 Test Facility

Test equipment and facilities will be utilized at both government and industry facilities. Appropriate facilities will be selected to simulate the interaction of identified adverse environments with specific TPS components fabricated in Task 4. Test facilities which have been identified are listed below.

- NASA-Ames arcjet facilities, 60 and 20 MW facilities
- NASA-Ames light gas gun
- AFWL rain impact facility
- Rockwell International rain/wind facility
- Rockwell International salt fog facility
- Rockwell International vibroacoustic facility
- Rockwell International radiant heat facility

Schedules and test requirements are defined in the detailed test description section of this document.

3.3 Instrumentation

All measurement instrumentation shall be calibrated and have a decal showing a valid calibration date. A list of all test instrumentation will be maintained in a Laboratory Notebook.

3.4 Test conduct

The test program will be conducted under the direction of the task leader or a designated representative.

4.0 SUBTASK DESCRIPTION

4.1 SELECT/PROVIDE AETB-12/AETB-8

4.1.1 Introduction/Background

All Task 4 testing will utilize the increased strength Alumina Enhanced Thermal Barrier (AETB) tile. Fabrication includes 12 lb/ft³ and 8 lb/ft³ AETB for use in the final three phases of Task 4. Current specimen requirements call for 157 coated and uncoated tiles ranging in size from 2-x-2-in coupons to 10-x-10-in tiles. All tiles requiring coating will be sprayed with Tuffened Unipiece Fiberous Insulation (TUF1).

4.1.2 Applicable Documents

*Production Unit Processing Record-Qualification Series

*TUF1 Coating Mix Requirements

*Molybdenum Disilicide Ball Milling

*Silica Hexaboride Ball Milling

*Silica Frit Ball Milling

*Note: Copy of document shown in sample data sheets are found starting on pg 36.

4.1.3 Detailed Requirements

The materials requirements of AETB fabrication are as listed below.

Silica Fiber

Nextel Fiber (AB-312, 3μ)

Saffil Fiber (5HA, 3.2μ)

Silicon Carbide (320 Grit)

Ammonium Hydroxide (Reagent Grade)

Surfactant (DC-193)

Deionized Water (\geq 1 megohm-cm)

4.1.4 Detailed Test Article/Test Specimen Description

The finished PU shall have the following properties.

Appearance: The specimen shall have no yellow or white spots.

Density: The density shall be between 11.0 and 13.0 lbs/ft³.

Tracibility: Each tile shall have impression markings on the side not to be coated for identification and traceability.

Machining: PU's shall be machined to the specific requirements called out in subtasks 4.3, 4.4, and 4.5.

4.1.5 Fabrication Procedure

AETB shall be fabricated using the procedures listed in the "Production Unit Processing Record - Qualification Series".

Coating: Coating shall be accomplished using TUFI.

Application: The TUFI shall be applied uniformly in three coats.

- 1st Coat: 3g/in²
- 2nd Coat: 3g/in²
- 3rd Coat: 1.5g/in²

All three coats are applied to the tile surface while, only the first coat is applied to the tile sidewalls.

4.1.6 Sample Data Sheets

Production Unit Processing Record-Qualification Series

TUFI Coating Mix Requirements

Molybdenum Disilicide Ball Milling

Silica Hexaboride Ball Milling

Silica Frit Ball Milling

4.1.7 Test Equipment

V- Blender, stainless steel, 1 ft³ min., intensifier bar.

Drying Oven, 350F capability.

Casting tower, 8-1/2-x-8-1/2-in and 14-x-14-in with vacuum assist degassing capability and Hydraulic Ram.

Kiln, 2500F capability

4.1.8 Schedule

Begin AETB-12 fabrication	July 11, 1994
Fabrication of AETB-12 complete	August 30,1994
Begin AETB-8 fabrication	September 1,1994
Fabrication of AETB-8 complete	December 23, 1994
Initiate fabrication of 10-x-10-in AETB-12	December 23,1994
All fabrication complete	February 15,1995

4.2 DIRECT BOND EVALUATION - Evaluate bonding of AETB tiles to graphite composite substrate without using strain isolator pads (SIP). Testing will include in-plane strain, deflection, system tensile strength, vibroacoustics and structural mismatch.

4.2.1 Introduction/Background

By direct bonding tile to a graphite bismalimide structure significant weight savings and/or thermal performance can be realized. The elimination of the strain isolator pad (SIP) is made possible by the similar coefficient of thermal expansion in the tile and graphite bismalimide substrate. With the elimination of SIP, substrate deflections must be limited by design to prevent TPS loss and damage. All testing in this subtask provides design allowables for structure deflection as to not damage the attached TPS.

Testing will include in-plane strain, substrate deflection, flatwise tension on single tile bonded to a graphite bismalimide substrate, and deflection, vibroacoustics, and structure mismatch deflection on seven tile arrays. Testing will be conducted at room temperature as well as various elevated temperatures.

4.2.2 Applicable Documents

MAO106-319 "RTV Silicon Adhesive-Bonded Silica Reusable Surface Insulation (RSI) System.

MBO130-119 TYII -RTV 560 Material Specification.

4.2.3 Direct Bond Detailed Requirements

All structure used in the direct bond task will be fabricated using composite graphite/bismalimide. Specimens requiring core will be bonded using American Cyanimide's HT424 adhesive.

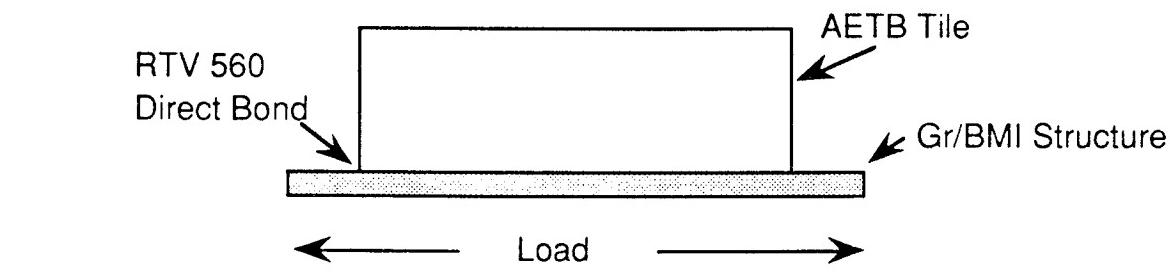
All AETB tile will be bonded to the structure using General Electric's RTV 560 silicon adhesive with a nominal bond line thickness of 7-10 mils.

4.2.3.1 IN-PLANE STRAIN (6b)

4.2.3.1.1 Detailed Test Article/Test Specimen Description

Three 6-x-6-in AETB-12 will each be bonded to a 8-x-12-in substrate. A 8-x-8-x-0.5-in aluminum core (9.5 lb/ft³ /3/8" cell) and a second composite facesheet will be adhesively bonded to the back of the structure. Four strain gauges will be placed on each specimen, two on the structure (one on each side of the tile in the load line), and two on the tile sidewalls 1/4" from the structure surface parallel to the load line.

In-Plane Strain



4.2.3.1.2 Test Procedures

The 8-in wide side of the laminate will be tabbed using 2-x-8-in tapered composite tab. 1.5-x-8-in load plates will be attached to the 8-in wide side of the structure. All testing will be conducted at room temperature. Load will be applied using a crosshead rate of 0.005 in/min. Load, strain, initial tile failure, and failure mode will be recorded.

4.2.3.1.3 Test Equipment

The test will be conducted using a MTS test machine with the load being applied using specially fabricated load fixtures.

4.2.3.1.4 Schedule

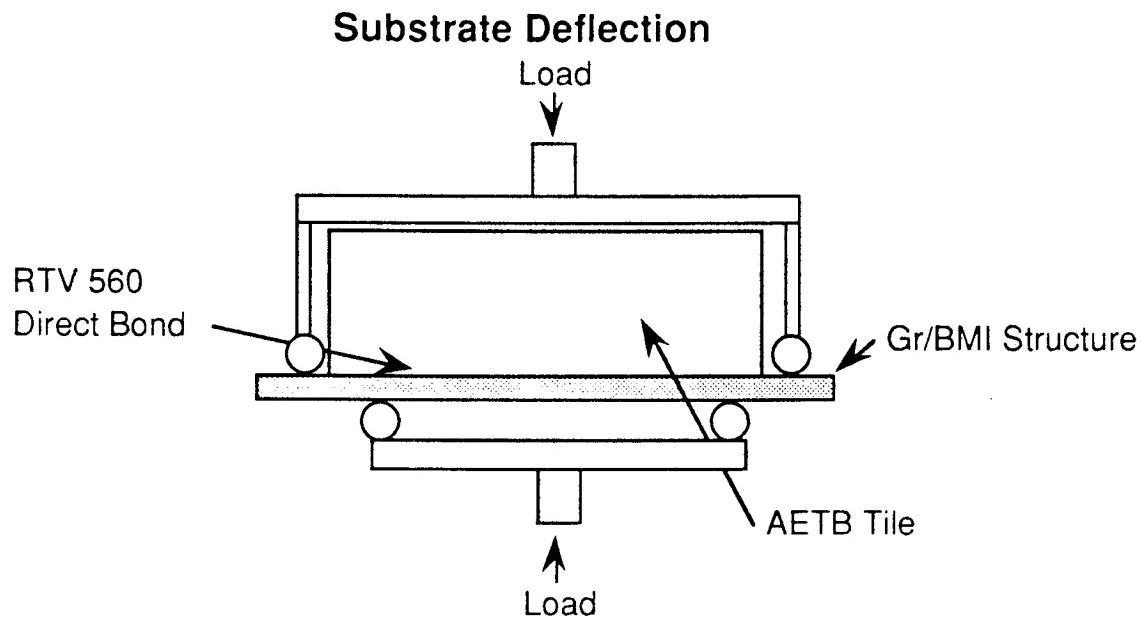
Initiate Specimen Fabrication
Complete in-plane strain testing

August 1, 1994
October 15, 1994

4.2.3.2 SUBSTRATE DEFLECTION (6c)

4.2.3.2.1 Detailed Test Article/Test Specimen Description

Five 6-x-6-in AETB-12, five 10-x-10-in AETB-12 and five 6-x-6-in AETB-8 will each be bonded to a 12-x-14-in substrate. Four strain gauges will be placed on each specimen, two on the structure (one on each side of the tile in the load line), and two on the tile sidewalls 1/4" from the structure surface. Three bending beam deflection gauges will be used to monitor substrate deflection at the center point and two tile edges. A schematic is shown below.



4.2.3.2.2 Test Procedures

Adjustable loading fixtures will be utilized to provide the proper spans to achieve the load case required. Load will be applied using a crosshead rate of 0.005 in/min. Load, strain, deflection, initial tile failure, and failure mode will be recorded.

4.2.3.2.3 Test Equipment

The test will be conducted using a MTS test machine. Cantilever bending beam gages will be utilized to measure substrate deflection. A computer program will provide bending beam and strain gauge output every second.

4.2.3.2.4 Schedule

Initiate specimen fabrication	October 15, 1994
Initiate fixture fabrication	October 15, 1994
Single tile deflection testing complete	December 23,1994
Fabrication and test of 10-x-10-in defl.	February 15,1995

4.2.3.3 System Flatwise Tensile Strength (6d)

4.2.3.3.1 Detailed Test Article/Test Specimen Description

Six 6-x-6-in AETB-12 and six 6-x-6-in AETB-8 will each be bonded to a 10-x-10-in substrate from TA-1 and Six 6-x-6-in AETB-12 and six 6-x-6-in AETB-8 will each be bonded a structure called out in TA-2. Three specimens of each will be tested in flatwise tensile (FWT) at room temperature and three will be tested at 350F. The matrix of tests is listed below.

Test Type	Substrate	TEST TEMP	
		R.T.	350°F
AETB-12	TA-1 (Tile/Foam/Structure)	3	3
	TA-2 (Tile/Structure)	3	3
AETB-8	TA-1 (Tile/Foam/Structure)	3	3
	TA-2 (Tile/Structure)	3	3

4.2.3.3.2 Test Procedures

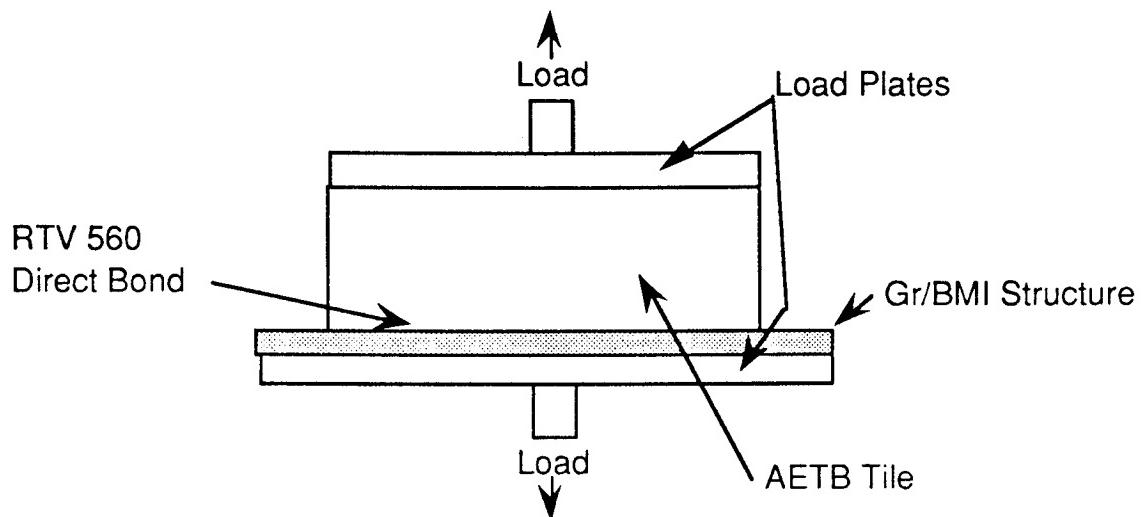
On all specimens (Tile/Foam/Structure & Tile/Structure) load plates must be applied to both surfaces. At room temperature 1/2" thick 6061 T6 aluminum load plates will be bonded to the structure side and the tile surface using Hysol EA 911 room temperature curing adhesive. At the elevated test temperature, steel load blocks will be bonded to the structure using American Cyanamides HT 424 structural adhesive. The tile must be initially bonded to a composite panel which is then bonded to the steel load block. Load will be applied using a crosshead rate of 0.005 in/min. Load vs crosshead movement, ultimate failure load, and failure mode will be recorded.

4.2.3.3.3 Test Equipment

The test will be conducted using a MTS test machine.

4.2.3.3.4 Sketches and Schematics

System Flatwise Tensile



4.2.3.3.5 Schedule

Initiate specimen fabrication
Complete specimen fabrication
Complete testing

October 15, 1994
December 1, 1994
December 23, 1994

4.2.3.4 ARRAY STRUCTURE DEFLECTION (6e)

4.2.3.4.1 Detailed Test Article/Test Specimen Description

One 15-x-40-in seven tile array.

4.2.3.4.2 Test Procedures

The panel deflection will be conducted at room temperature, 200F, 300F, and 400F. The panel will also be subjected to -250F with no deflection load applied. Tests will be performed first without tiles bonded to the structure. The substrate array panel will then have AETB-12 direct bonded, and the deflection tests repeated.

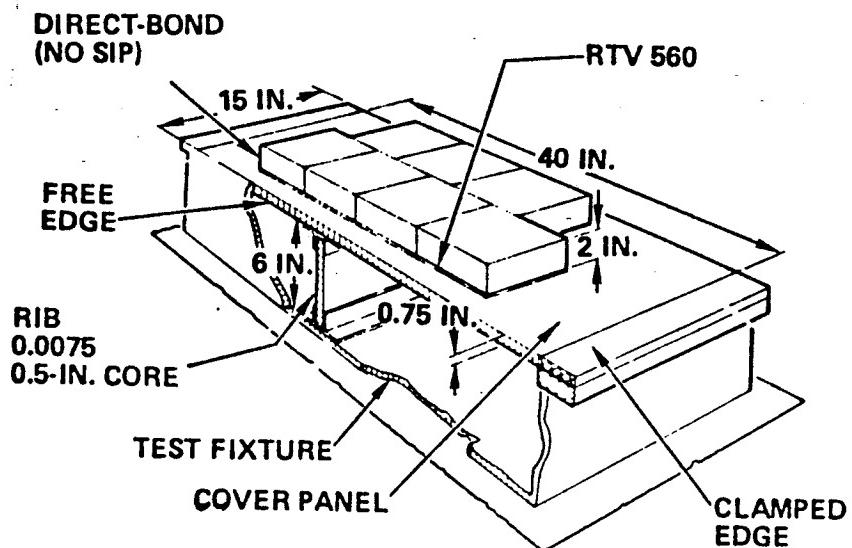
The test panel will be sealed in the "bathtub" fixture as shown in 4.2.3.4.4. Vacuum will be applied to produce a deflection in the panel. Twenty-three strain gauges will be bonded to the structure surface. Twelve deflection gauges will be attached to the panel and subjected as described. On completion of the panel deflection, tile will be bonded to the surface of the panel in a 4/3 staggered position as shown in 4.2.3.4.4. Additional deflection gauges will be attached (Approximately 30 total) and the deflection tests will be repeated.

4.2.3.4.3 Test Equipment

The test will be conducted in the "bathtub" fixture developed for the Rockwell International Space Shuttle orbiter "IR&D Project 202 Orbiter Subsystem Design Improvements. S/A 20200 Structural Weight Reductions".

Instrumentation will consist of Cantilever bending beam gauges and rosette/uniaxial strain gauges.

4.2.3.4.4 Sketches and Schematics



4.2.3.4.5 Schedule

Initiate specimen fabrication
Complete specimen fabrication
Testing deflection panel complete

October 1, 1994
June 30, 1996
April 30, 1996

4.2.3.5 ARRAY VIBROACOUSTIC PERFORMANCE (6f)

4.2.3.5.1 Detailed Test Article/Test Specimen Description

One 15-x-40-in seven tile array.

4.2.3.5.2 Test Procedures

Accelerometers will be applied to the panel (4.2.3.5.4) and it will be subjected to vibration and acoustic loading at progressive wave, 160 dB. The detailed test plan for the vibroacoustics is shown in Appendix H (DTP 6451-817).

4.2.3.5.3 Test Equipment

Test equipment is listed in Appendix H (DTP 6451-817).

4.2.3.5.4 Schedule

Initiate specimen fabrication	October 1,1994
Complete specimen fabrication	June 30,1996
Vibroacoustic testing, panel complete	April 30,1996

4.2.3.6 EFFECTS OF STRUCTURE MISMATCH (6g)

4.2.3.6.1 Detailed Test Article/Test Specimen Description

Composite substrates will be fabricated with built in structure mismatch (0.005", 0.010" and 0.015"). In the case of each mismatch AETB-12 and AETB-12 tile will be bonded over each mismatch as shown in 4.2.3.6.4.

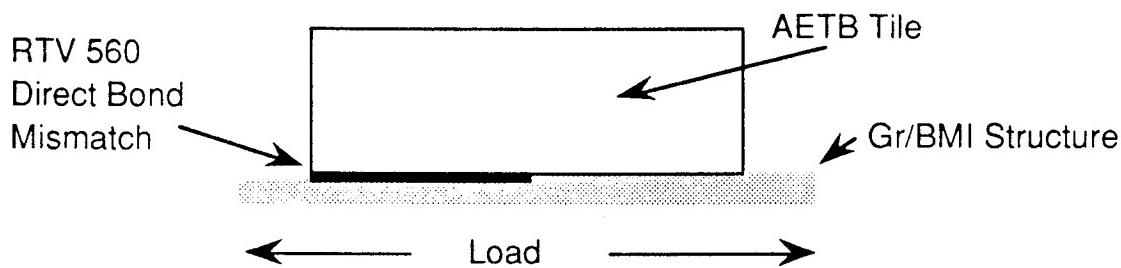
4.2.3.6.2 Test Procedure

Each specimen will be subject to bond verification using a vacuum chuck as described in MLO601-9024 "Process 315-Bond Verification". The specimens will then be exposed to a 1 hr 550F soak and the process will be repeated for three cycles. Specimen criteria are based on a pass fail basis.

4.2.3.6.3 Test Equipment

Test equipment to be utilized includes a vacuum chuck and other miscellaneous equipment called out in MLO601-9024 Process 315.

4.2.3.6.4 Sketches and Schematics



4.2.3.6.5 Schedule

Initiate specimen fabrication
Complete mismatch testing

October 1, 1996
January 19, 1996

4.3 VELCRO ATTACHMENT PROCESS DEVELOPMENT

4.3.1 Introduction/Background

The use of specialty Velcro has been suggested for attaching TPS components to vehicle structure or foam. Suitable candidates will be evaluated to verify their durability to the SSTO flight and operational environments. Velcro strength/durability will be evaluated on new material and after several removals. If strength and environmental durability are adequate, methods of attaching the Velcro to the tile, blankets and various substrates will be explored. A seven tile array will then be fabricated and exposed to humidity, wind/rain, and cold.

4.3.2 Applicable Documents

An Investigation of the Velcro Hi-Garde Metallic Hook and Loop Fastener System", NASA Ames Research Center, Angela L. Robinson.

4.3.3 Velcro Detailed Requirements

The Velcro supplied from the vendor shall be evaluated by the tests that follow.

4.3.3.1 EVALUATE VELCRO (6h)

4.3.3.1.1 Detailed Test Article/Test Specimen Description

4.3.3.1.2 Test Procedure

Testing will include:

Material identification/characterization.

Temperature capability.

Environmental resistance.

Humidity exposure.

Cryogenic Exposure

Ease of use.

Removal/installation.

Ability to conform to complex structure.

Attachment to TPS (tiles and blankets).

Strength/durability

Tensile before and after R&R

Peel before and after R&R

4.3.3.1.3 Test Equipment

MTS test machines, thermal and spectrographic equipment, and general laboratory equipment

4.3.3.1.4 Schedule

"Velcro" vendor search initiated

September 1, 1994

Velcro evaluation plan complete

November 15, 1994

Evaluation complete

February 15, 1995

4.3.3.2 VELCRO ATTACHMENT (6i)

4.3.3.2.1 Detailed Test Article/Test Specimen Description

Five 6-x-6-in tile and five 6-x-6-in blanket coupons will be fabricated using different methods of adhesive and mechanical attachment. Specimens will be adhesively bonded using RTV 560 (MBO130-119 TYII) of bondline thickness from 10 mils to 20 mils and by the use of a structural adhesive HT 424. For blankets, the adhesive bonding process and sewing the Velcro directly to the blanket will be examined.

4.3.3.2.2 Test Procedures

The specimens will be subjected to the 375°F for 1Hr and -160°F for 1Hr. The specimens will then be subjected to removal and replacement. Visual inspection will detect any anomalies which be recorded photographically

4.3.3.2.3 Test Equipment

All testing will be conducted using a MTS test machine

4.3.3.2.4 Sketches and Schematics

4.3.3.2.5 Schedule

Initiate Velcro TPS attachment process
Complete blanket and tile attachment

February 15,1995
June 30, 1995

4.3.3.3 VELCRO JOINT STRENGTH (6j)

This task will determine the strength of the Tile/Velcro/Structure system before and after several removals and re-application have been conducted.

4.3.3.3.1 Detailed Test Article/Test Specimen Description

Twenty 2-x-2-in, eight 6-x-6-in AETB-12 and two 12-x-12-in blankets attached to a composite substrate by the most promising method evaluated in 4.3.3.1.

4.3.3.3.2 Test Procedure

On all tile specimens load plates will be applied to the structure and tile surfaces. At room temperature, 1/2" thick 6061 T6 aluminum load plates will be bonded to the structure side and the tile surface using Hysol EA 911 room temperature curing adhesive. Load will be applied using a crosshead rate of 0.05 in/min. Load vs crosshead movement, ultimate failure load, and failure mode will be recorded.

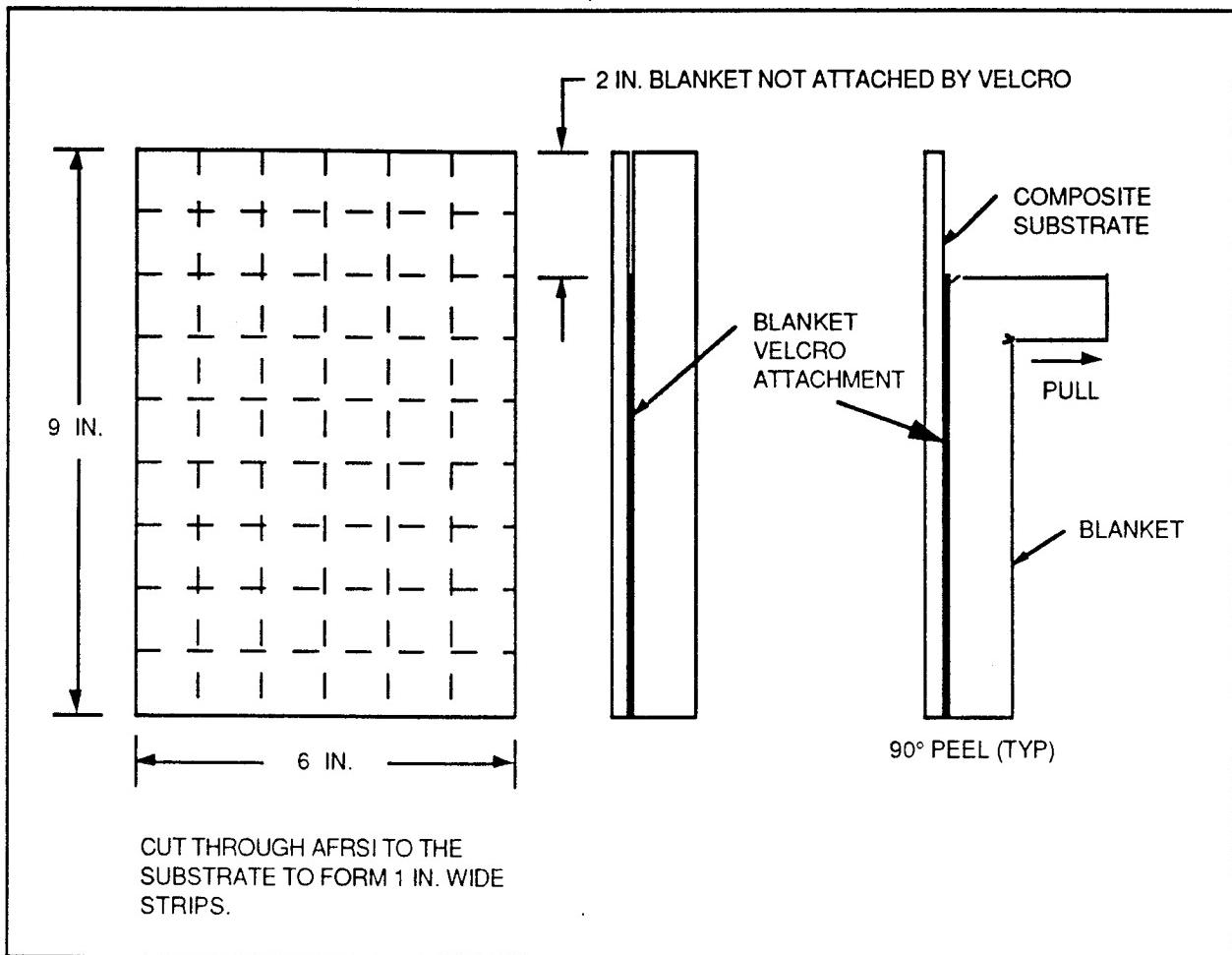
Blanket specimens shall be bonded to the structure and 1" strips shall be cut in from the surface of the blanket through to the structure. The 1" wide blanket strips shall be tested in peel per ASTM D 903.

4.3.3.3.3 Test Equipment

The test will be conducted using a MTS test machine.

4.3.3.3.4 Sketches and Schematics

ASTM D 903, BLANKET PEEL



4.3.3.3.5 Schedule

Initiate specimen fabrication
Perform joint strength testing

February 15, 1994
April 30, 1995

4.3.3.4 VELCRO ATTACHMENT AREA (6k)

This task will determine the attachment area required (tile/substrate) for attaching tile to the structure below. Also examined will be the vibroacoustic resilience and venting properties of a 24-x-24-in blanket attached to the structure using Velcro.

4.3.3.4.1 Detailed Test Article/Test Specimen Description

Five 6-x-6-in AETB-12 bonded using only a 5-x-5-in Velcro footprint, five 6-x-6-in AETB-12 bonded using 6-x-6-in Velcro footprint (full footprint) for use in flatwise tensile testing.

One 24-x-24-in blanket attached to an aluminum substrate using 24-x-24-in Velcro for use in vibroacoustic and venting tests.

4.3.3.4.2 Test Procedures

On all tile specimens load plates will be applied to the structure and tile surfaces. At room temperature, 1/2" thick 6061 T6 aluminum load plates will be bonded to the structure side and the tile surface using Hysol EA 911 room temperature curing adhesive. Load will be applied using a crosshead rate of 0.05 in/min. Load vs crosshead movement, ultimate failure load, and failure mode will be recorded.

The blanket specimen will be subjected to ascent/descent pressure profiles and examined for disbonds or any other anomalies. The blanket will then be subjected to vibroacoustics and venting as described in procedures listed in Appendix H (DTP 6451-817) and Appendix K (DTP 6451-820).

4.3.3.4.3 Test Equipment

Tensile tests will be conducted using a MTS test machine.
Venting requirements will be achieved in a environmental chamber.
Vibroacoustic loads will be applied using the equipment listed in Appendix H (DTP 6451-817)

4.3.3.4.4 Schedule

Initiate fabrication of test specimens
Perform joint strength test

February 15, 1995
April 30, 1995

4.3.3.5 VELCRO ENVIRONMENTAL EFFECTS (6I)

This task will determine the effects of humidity, wind/rain, salt spray and cryogenic exposure on Velcro attached tile and blankets. Analysis for GO₂ and GH₂ at the Velcro joint will be conducted to evaluate safety concerns.

4.3.3.5.1 Detailed Test Article/Test Specimen Description

Five 3-x-3-in AETB-12 tile coupons and five 6-x-6-in AFRSI blanket coupons.

One 15-x-40-in seven tile array and one 24-x-24-in blanket array.

4.3.3.5.2 Test Procedure

Expose five tile and three blanket coupons to the following conditions,
Humidity exposure, 80% R.H. 100°F for 120 hours.

Wind/Rain exposure will be conducted as is described in Appendix F
(DTP 6451-815).

Salt spray exposure, 7 day exposure as is described in ASTM B117

Cryogenic exposure, The coupons will be exposed to -150°F for 1
hour. This cycle will be repeated 10 times.

Flatwise tensile testing shall be conducted on all coupons and unexposed controls at room temperature and 0.05 in/min crosshead rate.

The two arrays (blanket and tile) will be subjected to launch pad conditions. Arrangements will be made with KSC to allow placement of the panels near the launch pad for a 60 day exposure. Visual inspection and photographic documentation will be recorded. Bond verification will be conducted per MLO601-924 "Process Bond Verification of RSI Tiles".

One tile and one blanket will be fitted with a capillary sampling tube embedded in the Velcro. The backface structure temperature will be cooled using LN₂. The Velcro interface will be monitored for any deviation from the normal concentration of GO₂ and GH₂ using multiple gas analyzers.

4.3.3.5.3 Test Equipment

Tensile tests will be conducted using a MTS test machine.

Humidity exposures will be conducted in a suitable chamber with controls capable of maintaining ± 3 °F and $\pm 5\%$ R.H. A chart shall be maintained documenting the actual temperature and humidity.

Wind/Rain exposures will be applied using the equipment listed in Appendix F.

Salt Spray exposure shall be conducted in a standard salt spray chamber as is listed in ASTM B117

Cryogenic exposure shall be accomplished using a test chamber fitted with a controlled LN₂ source.

4.3.3.5.4 Schedule

Initiate specimen fabrication	February 15,1995
Initiate adverse environments testing	August 31, 1995
Adverse data collection complete	September 30,1995

4.4 CMC COVER DEVELOPMENT

CMC tile cover attachment - A method of attachment will be developed/demonstrated by attaching it to the surface of an AETB-12 tile. Performance will be demonstrated by thermal exposure, deflection, vibration and impact.

4.4.1 Introduction/Background

Attachment of "Top Hat" Cover to TPS Tile". Ceramic tiles are very efficient and predictable TPS components, but they are easily damaged by debris and rain/cloud impacts. Flight/operational restrictions must be placed on a vehicle to protect the current tile systems from damage. One concept to limit or remove the need for such restrictions is to increase the "Tuffness" of the tile surface by attaching a ceramic matrix composite (CMC) to the tile surface. The attached CMC cover would increase the tile durability yet the system would remain an efficient insulator.

The CMC cover will be attached using mechanical methods. Attachment will be conducted on AETB-12 and AETB-8 tile substrates, first on coupon-size specimens then to 6-x-6-in tiles fabricated for radiant and arc jet thermal tests. CMC cover specimens will then be attached to GR/BMI substrate and tested for performance under substrate deflection, impact and vibroacoustic loading.

4.4.2 Applicable Documents

4.4.3 CMC Cover Detailed Requirements

All AETB tile will be bonded to the structure using General Electric's RTV 560 silicon adhesive with a nominal bond line thickness of 7-10 mils.

4.4.3.1 CMC COVER ATTACHMENT PROCESS DEVELOPMENT (6m)

This task will evaluate method of attaching CMC (C/SiC or SiC/SiC) to the outer surface of AETB -12 and AETB-8 production units (PU's). The methods to be evaluated include mechanical and bonding attachment.

4.4.3.1.1 Detailed Test Article/Test Specimen Description

Six 6-x-6-in AETB-12 tile and Six 6-x-6-in AETB-8 tile.

4.4.3.1.2 Test Procedures

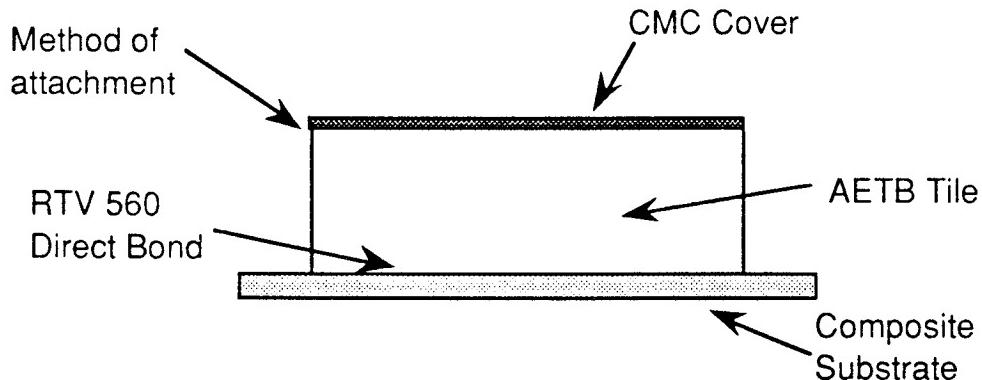
The test procedures will be developed using input data from Rockwell, NASA, and vendor data.

4.4.3.1.3 Test Equipment

TBD

4.4.3.1.4 Sketches and Schematics

CMC Cover Attachment



4.4.3.1.5 Schedule

Initiate vendor contacts/begin attachment	August 15, 1994
Demonstrate CMC tile attachment	April 30, 1996
Fabricate AETB-12 CMC test specimens	April 15, 1995
Fabricate AETB-8 CMC test specimens	June 30, 1995

4.4.3.2 CMC COVER THERMAL EVALUATION (6n)

This task will evaluate the performance of CMC/tile composite and its attachment method to radiant and arcjet thermal exposures.

4.4.3.2.1 Detailed Test Article/Test Specimen Description

one 1-x-6-x-6-in AETB-12 tile and one 1-x-6-x-6-in AETB-8 tile.

4.4.3.2.2 Test Procedures

Each specimen will be subjected to radiant exposures of 1500°F, 2000°F, and 2500°F using the method described in Appendix J (DTP 6451-819).

Each specimen will be tested using arcjet by the method described in Appendix A (DTP 6451-810)

4.4.3.2.3 Test Equipment

The test equipment utilized in radiant and arcjet testing is called out in Appendix J and Appendix A respectively.

4.4.3.2.4 Schedule

Initiate preparation of CMC test specimens	October 1,1995
Initiate testing of CMC specimens	June 30,1996

4.4.3.3 CMC COVER SUBSTRATE DEFLECTION (6o)

AETB-12 tile with attached CMC cover will be direct bonded using 0.090" thick strain isolator pad. The composite substrate will be subjected deflection loads until tile failure occurs.

4.4.3.3.1 Detailed Test Article/Test Specimen Description

Two 6-x-6-in AETB-12. One direct bonded to a composite substrate, one bonded to the substrate using 0.090" thick strain isolation pad. Four strain gauges will be placed on each specimen, two on the structure (one on each side of the tile in the load line), and two on the tile sidewalls 1/4" from the structure surface. Three bending beam deflection gauges will be used to monitor substrate deflection at the center point and tile two tile edges. A schematic is shown below.

4.4.3.3.2 Test Procedure

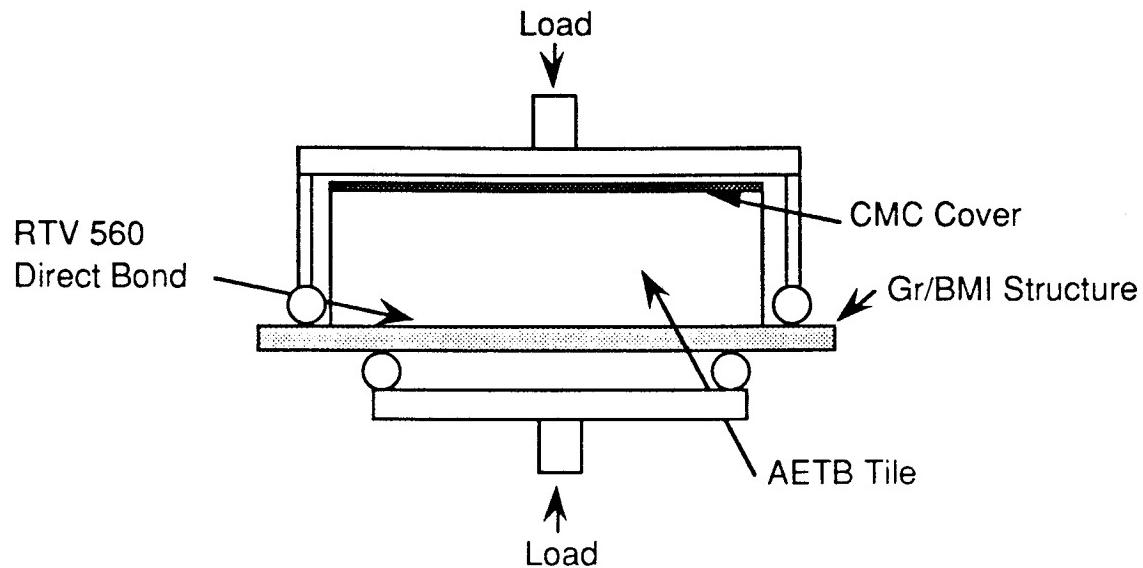
Adjustable loading fixtures will be utilized to provide the proper spans to achieve the load case required. Load will be applied using a crosshead rate of 0.005 in/min. Load, strain, deflection, initial tile failure, and failure mode will be recorded.

4.4.3.3.3 Test Equipment

The test will be conducted using a MTS test machine. Cantilever bending beam gages will be utilized to measure substrate deflection. A computer program will provide bending beam and strain gauge output every second.

4.4.3.3.4 Sketches and Schematics

CMC Cover Substrate Deflection



4.4.3.3.5 Schedule

Initiate preparation of CMC test specimens
Initiate testing of CMC specimens

October 1, 1995
June 30, 1996

4.4.3.4 CMC VIBROACOUSTIC PERFORMANCE (6p)

A seven tile array fabricated from CMC covered tiles will be subjected to vibroacoustic loads, 160 dB progressive wave.

4.4.3.4.1 Detailed Test Article/Test Specimen Description

One 15-x-40-in seven tile array will be fabricated using the most promising method of CMC cover attachment. The tile will be direct bonded to the composite substrate in a 4/3 tile staggered position allowing 0.02" gaps.

4.4.3.4.2 Test Procedures

Vibroacoustics will be applied and monitored using 160 dB, progressive wave, as described in Appendix H (DTP 6451-817).

4.4.3.4.3 Test Equipment

The vibroacoustic test will utilize the equipment listed in Appendix H

4.4.3.4.4 Schedule

Initiate preparation of CMC test specimens	October 1,1995
Initiate testing of CMC specimens	June 30,1996

4.4.3.5 CMC COVER IMPACT RESISTANCE (6g)

CMC covered tiles will be subjected to rain and debris impact.

4.4.3.5.1 Detailed Test Article/Test Specimen Description

Twenty 6-x-6-in CMC covered tiles will be direct bonded to a 1/8"-x-8-x-8-in aluminum substrate.

4.4.3.5.2 Test Procedures

Ten CMC covered tiles will be subjected to rain impact at WPAFB as directed in Appendix D (DTP 6451-813).

Ten CMC covered tiles will be subjected to debris impact using the AMES light gas gun as described in Appendix C (DTP 6451-812).

4.4.3.5.3 Test Equipment

The rain impact and debris impact will utilize the test equipment describe in Appendix D and Appendix C respectively.

4.4.3.5.4 Schedule

Initiate preparation of CMC test specimens	October 1,1995
Initiate testing of CMC specimens	June 30,1996

5.0 Sample Data Sheets

Production Unit Processing Record-Qualification Series
TUFI Coating Mix Requirements
Molybdenum Disilicide Ball Milling
Silica Hexaboride Ball Milling
Silica Frit Ball Milling

Rockwell International
Space Systems Division

RB] Refractory Block Insulation

Production Unit Processing Record - Qualification Series

Product: AETB-12, Cast Size 8.5 x 8.5

PU Ident: AETB-12-P _____

Materials	Mfgr	Lot No.	Baseline		Actual		M&P
Silica Fiber	Schuler Intnl		680	gms		gms	
Nextel Fiber (AB-312, 3μ)	3-M		120	gms		gms	
Saffil Fiber (5HA, 3.2μ)	ICI Americas		200	gms		gms	
Silicon Carbide (320 Grit)	Bueeler	RI 93-3348-01	20	gms		gms	
Ammonium Hydroxide	Reagent Grade	RI 93-D5369-01	5	ml		ml	
Surfactant (DC-193)	Dow Corning	RI 93D4530-01	0.5	gms		gms	
Deionized Water	Shop System	N/A	15,500	gms		gms	

Processing		Baseline	Actual		M&P
1 Disperse silica fiber with DIW. Record DIW weight.		6,500	gms	gms	
2 Disperse Nextel fibers, Saffil fibers and surfactant with DIW. <i>LET SIT 15 min.</i> Mix slurry for 15-30 seconds. Record DIW weight		8,900	gms	gms	
3 Disperse SiC powder with DIW		100	gms	gms	
4 Transfer slurries to V-Shell blender. Add SiC and NH4OH. Blend / chop slurry to desired consistency. Record time.		21	min	min	
5 Transfer slurry to casting tower and vacuum degas to remove bubbles. Record vacuum pressure and duration.		25	'Hg	'Hg	
6 Re-agitate settled slurry with mixer blade. Extract water from tower leaving excess over felt. Record felt height.		9.5±	inch	inch	
7 Compress slurry to billet height. Record height.		5 3/4	inch	inch	
8 Remove billet, weigh & measure cast block (Avg L x T).			gms	gms	
		8.5x5.75	inch	x	inch
9 Oven dry billet at 300°F. Record temperature and approximate elapsed time.		300	°F		°F
		16	hrs		hrs
10 Weigh & measure (Avg LxWxT) cool billet. Determine green density of billet.		994*	gms	gms	
		8.5x8.5x5.75	inch	x x	inch
		9.12	pcf		pcf
11 Sinter billet at required temperature. Record elapsed soak time and temperature. <i>INVERT P.U. FOR FIRING</i>		2460	°F		°F
		90	min		min
12 Weigh & measure (Avg LxWxT) cool billet. Determine density of sintered, pre-trimmed block.		956*	gms	gms	
		7.6x7.6x4.8	inch	x x	inch
		13.16	pcf		pcf
13 Trim billet to size. Weigh & measure (Avg LxWxT). Determine production unit density		760	gms	gms	
		7.4x7.4x4.4	inch	x x	inch
		12	pcf		pcf

Date Complete: _____

Technician: _____

(* Target only - to be adjusted as required)

M&P Engineer: _____

TUFI Coating Mix Requirements

Sheet 1

Mix Ratio	Concentrate Solution			Spray Solution			Total DNA	
	MoSi2	SiB6	SiO2	Weight	Add DNA	Total Weight		
1	4.0	1.4	15.5	20.9	35.1	56.0	7.5	42.0
2	8.0	2.8	31.0	41.8	70.2	112.0	14.9	84.0
3	12.0	4.2	46.5	62.7	105.3	168.0	22.4	126.0
4	16.0	5.6	62.0	83.6	140.4	224.0	29.9	168.0
5	20.0	7.0	77.5	104.5	175.5	280.0	37.3	210.0
6	24.0	8.4	93.0	125.4	210.6	336.0	44.8	252.0
7	28.0	9.8	108.5	146.3	245.7	392.0	52.3	294.0
8	32.0	11.2	124.0	167.2	280.8	448.0	59.7	336.0
9	36.0	12.6	139.5	188.1	315.9	504.0	67.2	378.0
10	40.0	14.0	155.0	209.0	351.0	560.0	74.7	420.0
11	44.0	15.4	170.5	229.9	386.1	616.0	82.1	462.0
12	48.0	16.8	186.0	250.8	421.2	672.0	89.6	504.0
13	52.0	18.2	201.5	271.7	456.3	728.0	97.1	546.0
14	56.0	19.6	217.0	292.6	491.4	784.0	104.5	588.0
15	60.0	21.0	232.5	313.5	526.5	840.0	112.0	630.0
16	64.0	22.4	248.0	334.4	561.6	896.0	119.5	672.0
17	68.0	23.8	263.5	355.3	596.7	952.0	126.9	713.9
18	72.0	25.2	279.0	376.2	631.8	1008.0	134.4	755.9
19	76.0	26.6	294.5	397.1	666.9	1064.0	141.9	797.9
20	80.0	28.0	310.0	418.0	702.0	1120.0	149.3	839.9
21	84.0	29.4	325.5	438.9	737.1	1176.0	156.8	881.9
22	88.0	30.8	341.0	459.8	772.2	1232.0	164.3	923.9
23	92.0	32.2	356.5	480.7	807.3	1288.0	171.7	965.9
24	96.0	33.6	372.0	501.6	842.4	1344.0	179.2	1007.9
25	100.0	35.0	387.5	522.5	877.5	1400.0	186.7	1049.9
26	104.0	36.4	403.0	543.4	912.6	1456.0	194.1	1091.9
27	108.0	37.8	418.5	564.3	947.7	1512.0	201.6	1133.9
28	112.0	39.2	434.0	585.2	982.8	1568.0	209.1	1175.9
29	116.0	40.6	449.5	606.1	1017.9	1624.0	216.5	1217.9
30	120.0	42.0	465.0	627.0	1053.0	1680.0	224.0	1259.9
31	124.0	43.4	480.5	647.9	1088.1	1736.0	231.5	1301.9
32	128.0	44.8	496.0	668.8	1123.2	1792.0	238.9	1343.9
33	132.0	46.2	511.5	689.7	1158.3	1848.0	246.4	1385.9
34	136.0	47.6	527.0	710.6	1193.4	1904.0	253.9	1427.9
35	140.0	49.0	542.5	731.5	1228.5	1960.0	261.3	1469.9
36	144.0	50.4	558.0	752.4	1263.6	2016.0	268.8	1511.9
37	148.0	51.8	573.5	773.3	1298.7	2072.0	276.3	1553.9
38	152.0	53.2	589.0	794.2	1333.8	2128.0	283.7	1595.9
39	156.0	54.6	604.5	815.1	1368.9	2184.0	291.2	1637.9
40	160.0	56.0	620.0	836.0	1404.0	2240.0	298.7	1679.9

MIX YIELD PER STANDARD BALL MIX CHARGE (GRAMS)

MDS	SHB	SIF
500	250	370

APPLICATION RATE:

7.5 GRAMS / SQUARE INCH

Dick Hammons, D/361, 6-5-93

DTP L448-801
Sample Data Sheet

TUFI Coating Processing Record
Molybdenum Disilicide Ball Milling

(MoSi₂ - 95.5% Pure - 325 Mesh - Standard Roll Time 65 Hours)

RI CONTROL NO.	MFGR LOT NO.	MoSi ₂	DNA	RPM	JAR SIZE	ELAPSED HRS	PSD	COMMENTS	DATE
RBI-MDS-001	CERAC 52129-A-(1-6)A	392.7 GMS	168.3 GMS	81	#00	65.0	1.51 μ	WEIGHING ERROR, DISCARDED	6/10/93
RBI-MDS-002	CERAC 52129-A-(1-6)A	392.7 GMS	168.3 GMS	80	#00	65.1	1.20 μ		6/21/93
RBI-MDS-003	CERAC 52129-A-(1-6)A	392.7 GMS	168.3 GMS	80	#00	92.6	μ		8/12/93
RBI-MDS-004	CERAC 52129-A-(1-6)A	392.7 GMS	168.3 GMS	80	#00	63.3	μ		8/16/93
RBI-MDS-005	CERAC 52129-A-(1-6)A	392.7 GMS	168.3 GMS	80	#00	NA	μ	TIMING ERROR, DISCARDED	
RBI-MDS-006	CERAC 52129-A-(1-6)A	392.7 GMS	168.3 GMS	80	#00	50.0	1.05 μ	STOPPED INTERMITTENTLY	9/24/93
RBI-MDS-007	CERAC 52129-A-(1-6)A	392.7 GMS	168.3 GMS	80	#00	50.0	μ		10/19/93
RBI-MDS-008	"	392.7 GMS	168.3 GMS	80	#00	40.5	μ		3/17/94
RBI-MDS-009	"	392.7 GMS	168.3 GMS	80	00		μ		4/26/94
RBI-MDS-010	"	392.7 GMS	168.3 GMS	80	#00		μ		5/4/94
RBI-MDS-011		392.7 GMS	168.3 GMS				μ		
RBI-MDS-012		392.7 GMS	168.3 GMS				μ		
RBI-MDS-013		392.7 GMS	168.3 GMS				μ		
RBI-MDS-014		392.7 GMS	168.3 GMS				μ		
RBI-MDS-015		392.7 GMS	168.3 GMS				μ		
RBI-MDS-016		392.7 GMS	168.3 GMS				μ		
RBI-MDS-017		392.7 GMS	168.3 GMS				μ		
RBI-MDS-018		392.7 GMS	168.3 GMS				μ		
RBI-MDS-019		392.7 GMS	168.3 GMS				μ		
RBI-MDS-020		392.7 GMS	168.3 GMS				μ		
RBI-MDS-021		392.7 GMS	168.3 GMS				μ		
RBI-MDS-022		392.7 GMS	168.3 GMS				μ		
RBI-MDS-023		392.7 GMS	168.3 GMS				μ		
RBI-MDS-024		392.7 GMS	168.3 GMS				μ		
RBI-MDS-025		392.7 GMS	168.3 GMS				μ		
RBI-MDS-026		392.7 GMS	168.3 GMS				μ		
RBI-MDS-027		392.7 GMS	168.3 GMS				μ		
RBI-MDS-028		392.7 GMS	168.3 GMS				μ		
RBI-MDS-029		392.7 GMS	168.3 GMS				μ		
RBI-MDS-030		392.7 GMS	168.3 GMS				μ		

TUFI Coating Processing Record
Silica Hexaboride Ball Milling

(SiB6 - 98% Pure - 200 Mesh - Standard Roll Time 3 Hours)

DTP 644B-801
Sample Data Sheet

RI CONTROL NO.	MFGR LOT NO.	SIB6	DNA	RPM	JAR SIZE	ELAPSED	PSD	COMMENTS	DATE
RBI-SHB-001	CERAC 36166-A-4	65.6 GMS	196.8 GMS	82	#00	2.5	2.48 μ	WEIGHING ERROR, DISCARDED	6/10/93
RBI-SHB-002	CERAC 36166-A-4	65.6 GMS	196.8 GMS	80	#00	3.3	1.75 μ		6/21/93
RBI-SHB-003	CERAC 36166-A-4	65.6 GMS	196.8 GMS	80	#00	2.5	μ		6/25/93
RBI-SHB-004	CERAC 36166-A-4	65.6 GMS	196.8 GMS	80	#00	2.5	1.30 μ		10/19/93
RBI-SHB-005	CERAC 36166-A-4	65.6 GMS	196.8 GMS	80	#00	2.5	μ		12/10/93
RBI-SHB-006	CERAC 36166-A-4	65.6 GMS	196.8 GMS				μ		
RBI-SHB-007	CERAC 36166-A-4	65.6 GMS	196.8 GMS				μ		
RBI-SHB-008	CERAC 36166-A-4	65.6 GMS	196.8 GMS				μ		
RBI-SHB-009	CERAC 36166-A-4	65.6 GMS	196.8 GMS				μ		
RBI-SHB-010	CERAC 36166-A-4	65.6 GMS	196.8 GMS				μ		
RBI-SHB-011		65.6 GMS	196.8 GMS				μ		
RBI-SHB-012		65.6 GMS	196.8 GMS				μ		
RBI-SHB-013		65.6 GMS	196.8 GMS				μ		
RBI-SHB-014		65.6 GMS	196.8 GMS				μ		
RBI-SHB-015		65.6 GMS	196.8 GMS				μ		
RBI-SHB-016		65.6 GMS	196.8 GMS				μ		
RBI-SHB-017		65.6 GMS	196.8 GMS				μ		
RBI-SHB-018		65.6 GMS	196.8 GMS				μ		
RBI-SHB-019		65.6 GMS	196.8 GMS				μ		
RBI-SHB-020		65.6 GMS	196.8 GMS				μ		
RBI-SHB-021		65.6 GMS	196.8 GMS				μ		
RBI-SHB-022		65.6 GMS	196.8 GMS				μ		
RBI-SHB-023		65.6 GMS	196.8 GMS				μ		
RBI-SHB-024		65.6 GMS	196.8 GMS				μ		
RBI-SHB-025		65.6 GMS	196.8 GMS				μ		
RBI-SHB-026		65.6 GMS	196.8 GMS				μ		
RBI-SHB-027		65.6 GMS	196.8 GMS				μ		
RBI-SHB-028		65.6 GMS	196.8 GMS				μ		
RBI-SHB-029		65.6 GMS	196.8 GMS				μ		
RBI-SHB-030		65.6 GMS	196.8 GMS				μ		

TUFI Coating Processing Record

Silica Frit Ball Milling

DTP 6448-801
Sample Data Sheet

(SIO2 - MBO115-013 Type II/LAC42-4561-3000 - Standard Roll Time 65 Hours)

RI CONTROL NO.	MFGR LOT NO.	SIO2	DNA	RPM	JAR SIZE	ELAPSED HRS.	PSD	COMMENTS	DATE
RBI-SIF-001	RI #16-6V-HT (LMSC)	275.8 GMS	118.2 GMS	81	#00	65.0	2.44 μ	WEIGHING ERROR, DISCARDED	6/10/93
RBI-SIF-002	RI #16-6V-HT (LMSC)	275.8 GMS	118.2 GMS	80	#00	65.1	2.08 μ		6/21/93
RBI-SIF-003	RI #16-6V-HT (LMSC)	275.8 GMS	118.2 GMS	80	#00	65.0	2.04 μ		8/9/93
RBI-SIF-004	RI #16-6V-HT (LMSC)	275.8 GMS	118.2 GMS	80	#00	65.0	2.19 μ		8/25/93
RBI-SIF-005	RI #16-6V-HT (LMSC)	275.8 GMS	118.2 GMS	80	#00	65.0	2.19 μ	* SEE PSD TEST SHEET	
RBI-SIF-006	RI #16-6V-HT (LMSC)	275.8 GMS	118.2 GMS	80	#00	65.0	2.19 μ	* SEE PSD TEST SHEET	
RBI-SIF-007	RI #16-6V-HT (LMSC)	275.8 GMS	118.2 GMS	80	#00	65.0	2.19 μ	* SEE PSD TEST SHEET	9/24/93
RBI-SIF-008	RI #16-6V-HT (LMSC)	275.8 GMS	118.2 GMS	80	#00	65.0	2.02 μ	COMPLETED AT PLM	9/28/93
RBI-SIF-009	RI #16-6V-HT (LMSC)	275.8 GMS	118.2 GMS	80	#00	65.0	2.13 μ	COMPLETED AT PLM; *SEE PSD TEST SHEET	9/28/93
RBI-SIF-010	RI #16-6V-HT (LMSC)	275.8 GMS	118.2 GMS	80	#00	65.0	2.13 μ	LATER RE-AGITATED FOR 1 HR; *SEE PSD	9/29/93
RBI-SIF-011	RI #16-6V-HT (LMSC)	275.8 GMS	118.2 GMS	80	#00	65.0	1.99 μ		
RBI-SIF-012	RI #16-6V-HT (LMSC)	275.8 GMS	118.2 GMS	80	#00	65.0	μ		
RBI-SIF-013	RI #16-6V-HT (LMSC)	275.8 GMS	118.2 GMS	80	#00	65.0	2.20 μ	* SEE PSD TEST SHEET	
RBI-SIF-014	RI #16-6V-HT (LMSC)	275.8 GMS	118.2 GMS	80	#00	65.0	2.19 μ	* SEE PSD TEST SHEET	
RBI-SIF-015	RI #28J051 (KSC)	275.8 GMS	118.2 GMS	80	#00	65.0	μ		12/14/93
RBI-SIF-016	RI #28J051 (KSC)	275.8 GMS	118.2 GMS	80	#00	65.0	μ		12/14/93
RBI-SIF-017	"	1320	570	61	*1	50.5	μ	RPM CHANGED DURING ROLL	3/19/4
RBI-SIF-018	"	1230	275.8 GMS	70	118.2 GMS		μ		4/26/4
RBI-SIF-019			275.8 GMS	118.2 GMS			μ		
RBI-SIF-020			275.8 GMS	118.2 GMS			μ		
RBI-SIF-021			275.8 GMS	118.2 GMS			μ		
RBI-SIF-022			275.8 GMS	118.2 GMS			μ		
RBI-SIF-023			275.8 GMS	118.2 GMS			μ		
RBI-SIF-024			275.8 GMS	118.2 GMS			μ		
RBI-SIF-025			275.8 GMS	118.2 GMS			μ		
RBI-SIF-026			275.8 GMS	118.2 GMS			μ		
RBI-SIF-027			275.8 GMS	118.2 GMS			μ		
RBI-SIF-028			275.8 GMS	118.2 GMS			μ		
RBI-SIF-029			275.8 GMS	118.2 GMS			μ		
RBI-SIF-030			275.8 GMS	118.2 GMS			μ		

27 July, 1994

LIGHTWEIGHT DURABLE TPS: ROBUSTNESS TESTING

Task 5

**NCC2-9003
TA 3**

Task Leader: Eric T. Watts, Rockwell - SSD

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1.0 BACKGROUND

Advanced thermal protection system (TPS) materials will require quantitative characterization with respect to performance in the various adverse environments which impact an SSTO vehicle's outer surface. This plan describes the analysis and testing needed to demonstrate the robustness of Lightweight Durable TPS. Environmental concerns include the following;

Launchpad Environment:

- Launch pad wind-driven rain,
- Frost formation within blankets, and its impact on performance,
- Ice formation between tiles, and its impact on performance,
- Corrosive effects of salt spray,
- Effects of lightning strike,

Flight Environment:

- In-flight rain impact,
- Flight impacts from ice crystals and/or hail,
- Atmosphere re-entry heating performance,
- Aerodynamic surface loads,

Orbit Environment:

- Orbital impacts from micrometeoroids and space debris,

Analysis will be performed to define these natural environments and, from them, determine the impact on specific TPS materials. Requirements for testing will be determined from the location of specific TPS materials on the proposed SSTO vehicle and identified flight parameters. Testing under this task will be used to demonstrate the robustness of TPS materials under realistic, simulated flight conditions.

Materials for testing will be developed in tasks 1, 2, and 4 of this TA and are not yet specifically defined. These materials will include fluted core flexible blankets, flexible TPS with multi-layer insulation (MLI) and/or a metal foil outer surface, and alumina enhanced thermal barrier (AETB) tiles utilizing advanced attachment methods and durable ceramic matrix composite (CMC) covers. The durability of damaged and repaired TPS materials will be proved through exposure to simulated mission environments.

2.0 GENERAL REQUIREMENTS

Documentation

Detailed test procedure (DTP)

All testing will be conducted in accordance with this test procedure.

Laboratory Notebook

A Laboratory Notebook will be maintained by the Rockwell Responsible Test Engineer (RTE) during all phases of testing described in this test plan. Test configuration, instrumentation, test anomalies and all other pertinent data will be recorded.

Test Report

The Rockwell responsible test engineer will issue a Laboratory Test Report (LTR) for each appropriate test phase. Each test report will document apparatus, procedures, data, results, and any other pertinent information.

Test Facility

Test equipment and facilities will be utilized at both government and industry facilities. Appropriate facilities will be selected to simulate the interaction of identified adverse environments with specific TPS specimens fabricated in Tasks 1,2 and 4. Test facilities which have been identified are listed below.

- NASA-Ames arcjet facilities, 60 and 20 MW facilities
- NASA-Ames light gas gun
- NASA-Ames wind tunnel facility
- AFWL rain impact facility and/or General Research single drop impact facility
- Rockwell International cryogenic tank insulation testing
- Rockwell International rain/wind facility
- Rockwell International salt spray environment facility
- Rockwell International vibro-acoustic facility
- Rockwell International radiant heat facility

Schedules and test requirements are defined in the detailed test description section of this document.

Instrumentation

All measurement instrumentation shall be calibrated and have a decal showing a valid calibration date. A list of all test instrumentation will be maintained in a Laboratory Notebook.

Test Conduct

The test program will be conducted under the direction of the task leader or a designated representative.

3.0 SUBTASK DESCRIPTIONS

3.1 DEFINE ADVERSE ENVIRONMENTS

3.1.1 Applicable Documents

The documents listed below form a working list of reference material that will be utilized in the quantitative definition of the adverse environments previously mentioned.

1. Meteoroid and Space Debris Environment Definition. Don Kessler NASA reference document.
2. Orbital Debris Environment: An Update. Phan D. Dao, Phillips Laboratory, Geophysics Directorate, Hanscom AFB, MA. AIAA 94-0592
3. Space Station Program Natural Environment Definition For Design. Revision A-June ,1991. NASA Space Station Freedom Program Office, Reston Virginia
4. LDEF Post Retrieval Symposium, Part One and Part Two. NASA Conference Publications, AIAA
5. U.S. Weather Service Meteorological Data.

3.1.2 Detailed Requirements

A quantitative definition of adverse environments will be compiled from analysis of open literature, NASA and Rockwell technical reports, and all other available sources. Some environments listed are well understood and testing for performance in these presents little difficulty. Others, such as rain, ice and meteor impact are not as well defined. Here the analysis on environment definition will help drive testing requirements. Sections 3.1.2.1 through 3.1.2.3 detail present concerns with respect to initial definitions.

3.1.2.1 Launchpad Environments

Adverse environments associated with the launchpad include wind driven rain, the corrosive effects of salt air, and lightning discharge. Also of concern is the interaction of rain and humidity with a filled cryogenic tank and the potential for ice and frost formation. Wind driven rain, salt air conditions, and lightning strikes are defined, and standard test methods will be employed. Evaluation of potential ice and frost formation will require analysis to define characteristic temperatures of concept tank systems. The result of such analysis will define the impact on specific TPS materials and test conditions.

3.1.2.2 Flight Environments

Aerodynamic and thermal analysis, based on the Rockwell SSTO vehicle design, will be performed to define reentry heating and aerodynamic loads. Specific body point environments will form the basis for defining specific TPS material test requirements.

Analysis of flight impact phenomena (rain/ice/hail) will focus on defining weather conditions in terms of quantitative data such as drop size distribution, altitude profiles, etc.. The potential for relaxing the current restrictions of no flight through rain/clouds will be evaluated. This work will also include an analysis to determine the interaction of rain drops and ice with the flow field of the SSTO vehicle. This will provide necessary data on impact angles and drop distortion levels at different locations on the vehicle. All analysis will be utilized to define accurate test conditions for specific TPS materials.

3.1.2.3 Orbital Environments

Of primary concern in orbit is the potential for catastrophic impact from meteoroids and space debris. Current meteoroid and space debris environment models will be analyzed together with identified vehicle attitudes and TPS material locations to determine the most probable damaging particle sizes. Critical damage levels will be identified along with estimates of particle profiles capable of causing such damage. Testing methodology will flow from this analysis.

3.1.3 Schedule

Adverse environments definitions complete	15 October 1994*
TPS/environment relationship definition complete	15 November 1994*

* Formal Milestone

3.2 DEFINE TEST METHODS

It is the objective of this subtask to define test methods and specific operating parameters to demonstrate the performance of TPS materials in adverse conditions. Available test methods will be reviewed and their capabilities compared to the requirements identified in the previously described analysis. Methods, procedures, and operating parameters defined under this task will provide a comprehensive plan for testing described in the remainder of this plan (sections 3.3 through 3.7).

3.2.1 Applicable Documents

The following will represent a working reference list of documents for evaluating adverse environment simulating test methods.

1. ASTM standard test procedures
2. Facilities Capabilities

3.2.2 Schedule

Potential methods identified	1 November 1994
Test methods selected	1 April 1995
Testing defined for adverse environments	30 June 1995*

* Formal Milestone

3.3 RAIN EXPOSURE TESTING

Testing will be performed to expose TPS materials to simulated rain at launch and landing velocities. Primary objectives in this testing will be twofold; 1) to establish a baseline for material comparison and 2) to evaluate material performance in the actual rain environment. The potential for flight through rain will be evaluated. Two test methods have been identified for this testing, the standard rotating-arm type test and so called single water drop impact testing. Single water drop testing allows impact of varied and precisely known drop sizes, allowing for analytic correlation with the natural rain environment. Rotating arm testing can be used as a basis for comparing materials. A test program including both types of testing is recommended. Details are TBD.

Wind-driven rain will be simulated and exposure tests conducted to investigate the effects of launch pad weather on TPS blankets. Testing will be performed by blowing simulated rain at selected test specimens.

3.3.1 Applicable Documents

1. Appendix D, Standard Test Procedure - Rain Impact (Rotating Arm Facility)
2. Appendix E, Standard Test Procedure - Rain Impact (Single Drop Impact Facility)
3. Appendix F, Standard Test Procedure - Rain and Wind Impingement

3.3.2 Detailed Requirements

Detailed requirements for testing will be defined upon completion of subtask 3.2 described in this document.

3.3.3 Test Article

Detailed drawings of test articles will be included in the final test plan and will conform to dimensions required by the test facility. General articles to be tested are listed below.

Wind/Rain Testing - 1 @ 15" tile array with durable cover
- 1 @ 15"x 40" blanket on foam substrate

Rain Impact Testing - Method(s) TBD
- 20 @ tile with durable cover
- 20 @ blanket with metallic skin or ?

3.3.4 Test Procedure

Standard test procedures of the performing laboratories will be followed. Exceptions will be documented in this test plan.

3.3.5 Equipment/Facilities

Rotating arm rain erosion testing will be performed at the Air Force Facility, Wright Laboratories / Materials Directorate (WL/MD). Single drop impact testing is available at General Research Corporation, Santa Barbara, Ca. Rain and wind impingement, simulating launchpad conditions, will be performed at Rockwell - Laboratories, Test, and Materials Science Department.

3.3.6 Schedule

Begin test specimen design/fabrication	30 June 1995
Begin wind/rain testing (Rockwell)	30 November 1995*
WL/MD rain erosion testing (scheduled)	March-April 1996
Rain testing complete	30 July 1996*

* Formal Milestone

3.4 FROST FORMATION TESTING

Cryogenic tanks may cause the formation of frost within TPS blankets. Frost may then impact blanket performance during flight. Testing will be performed to determine if frost will form when blankets are installed over an insulated cryogenic tank. If frost does form, then additional testing, to simulate mission environments, will be performed to investigate potential adverse effects.

3.4.1 Applicable Documents

1. Appendix B - Standard Test Procedure - Wind Tunnel Testing
2. Appendix K - Standard Test Procedure - Venting
3. Appendix H - Standard Test Procedure - Vibro-acoustics
4. Appendix A - Standard Test Procedure - Arcjet Facilities

3.4.2 Detailed Requirements

Detailed requirements for testing will be defined upon completion of subtask 3.2 described in this document.

3.4.3 Test Article

Detailed drawings of test articles will be included in the final test plan and will conform to dimensions required by the test facility. General articles to be tested are listed below.

Frost Formation Testing - blanket installed over foamed cryogenic tank

Frosted Blanket Simulated Mission Performance Testing -
1 @ 30"x 30" blanket on foam over Aluminum substrate

3.4.4 Test Procedure

Standard test procedures of the performing laboratories will be followed. Exceptions will be documented in this test plan.

3.4.5 Equipment/Facilities

Frost formation, vibro-acoustic, pressure profile, and cold soak testing will be performed at Rockwell - Laboratories Test and Materials Science Department. Arcjet atmospheric entry heating simulation and wind tunnel tests will be performed at NASA -Ames.

3.4.6 Schedule

Begin test specimen design/fabrication	1 May 1995
Begin test setup	1 July 1995
Begin frost testing	15 September 1995
Frost testing complete - effects known	29 February 1996*

* Formal Milestone

NOTE: No time has been scheduled for arcjet testing or wind tunnel testing

3.5 ICE FORMATION TESTING

Cryogenic tanks may cause the formation of ice in tile gaps. Ice may then impact tile performance during flight. Testing will be performed to determine if ice will form when tile is installed over an insulated cryogenic tank. If ice does form, then additional testing, to simulate mission environments, will be performed to investigate potential adverse effects.

3.5.1 Applicable Documents

1. Appendix A - Standard Test Procedure - Arcjet Testing
2. Appendix K - Standard Test Procedure - Venting Testing
3. Appendix H - Standard Test Procedure - Vibro-acoustic Testing

3.5.2 Detailed Requirements

Detailed requirements for testing will be defined upon completion of subtask 3.2 described in this document.

3.5.3 Test Article

Detailed drawings of test articles will be included in the final test plan and will conform to dimensions required by the test facility. General articles to be tested are listed below.

Ice Formation Testing - five tile array installed over foamed cryogenic tank

**Simulated Mission Performance Testing -
Tile array on foam over Aluminum substrate**

3.5.4 Test Procedure

Standard test procedures of the performing laboratories will be followed. Exceptions will be documented in this test plan.

3.5.5 Equipment/Facilities

Frost formation, vibro-acoustic, pressure profile, and cold soak testing will be performed at Rockwell - Laboratories Test and Materials Science Department. Arcjet atmospheric entry heating simulation and wind tunnel tests will be performed at NASA -Ames.

3.5.6 Schedule

Begin test specimen design/fabrication	1 October 1995
Begin ice testing	1 December 1995
Ice testing complete - effects known	29 February 1996*

* Formal Milestone

NOTE: No time has been scheduled for arcjet testing - 60MW facility required.

3.6 IMPACT RESISTANCE TESTING

Hypervelocity impact testing will be performed to quantify potential damage from meteoroids and space debris. Testing will encompass damaging particle sizes most likely to be encountered in LEO orbits. Objectives for this testing include the establishment of particle sizes capable of causing "critical" damage and other threshold damage levels. Analysis will be performed to evaluate damage at high, and experimentally inaccessible, velocities characteristic of meteoroids.

Testing will be performed to assess damage susceptibility from ice crystals and hail impact. Specific natural environments will be simulated to evaluate damage and the potential for flight through these environments. The single drop facility at General Research Corporation can provide this testing. Additional test methods will be sought and evaluated for ice/hail impact testing.

TPS will be subjected to low velocity impacts to evaluate the resistance to "handling" type impacts such as wrench drops.

3.6.1 Applicable Documents

1. Appendix C- Standard Test Procedure - Debris Impact Testing
2. *Appendix E - Standard Test Procedure - Rain Impact (Single Drop)*

3.6.2 Detailed Requirements

Detailed requirements for testing will be defined upon completion of subtask 3.2 described in this document.

3.6.3 Test Article

Detailed drawings of test articles will be included in the final test plan and will conform to dimensions required by the test facility. General articles to be tested are listed below.

Meteoroid and Space Debris Testing - 10 @ blanket bonded to structure
 - 10 @ tile bonded to structure

Ice/Hail Impact Testing - 20 @ blanket coupons
 - 20 @ tile coupons

Low Velocity Testing - 20-30 TPS coupons

3.6.4 Test Procedure

Standard test procedures of the performing laboratories will be followed. Exceptions will be documented in this test plan.

3.6.5 Equipment/Facilities

Hypervelocity impact testing will be performed at NASA-Ames. Ice/hail testing facility TBD. Low velocity Impact testing will be performed at Rockwell - Laboratories, Tests and Materials Science Department.

3.6.6 Schedule

Begin specimen design/fabrication	1 April 1995
Begin low velocity impact testing	1 March 1996
Hypervelocity impact testing	April 1996
Ice/hail impact testing	?
Impact testing complete - effects known	30 July 1996*

* Formal Milestone

NOTE: No ice/hail impact testing scheduled

3.7 DAMAGE REPAIRS AND PERFORMANCE EVALUATION

An industry survey will identify repair materials and processes for TPS tiles and blankets. Testing will be performed to evaluate the performance of both repaired and unrepairs TPS materials. Simulated flight damage will be subjected to reentry conditions to determine survivable damage levels. Repaired TPS materials will be subjected to sequenced mission environments simulating ascent, orbit, and decent. This testing will serve to verify the utility of repair methods.

3.7.1 Applicable Documents

1. Appendix K - Standard Test Procedure - Venting Testing
2. Appendix H - Standard Test Procedure - Vibro-acoustic Testing
3. Appendix A - Standard Test Procedure - Arcjet Testing
4. Appendix B - Standard Test Procedure - Wind Tunnel Testing

3.7.2 Detailed Requirements

Detailed requirements for testing will be defined upon completion of subtask 3.2 described in this document.

3.7.3 Test Article

Detailed drawings of test articles will be included in the final test plan and will conform to dimensions required by the test facility. General articles to be tested are listed below.

Unrepaired, Damaged TPS Reentry Simulation Testing

- 10 @ blankets with various levels of damage
- 10 @ tiles with various levels of damage

Damaged, Repaired TPS Mission Simulation Testing

- 1 @ 24"x 24" blanket specimen w/repairs damage
- 1 @ tile array specimen w/repairs damage

3.7.4 Test Procedure

Standard test procedures of the performing laboratories will be followed. Exceptions will be documented in this test plan.

3.7.5 Equipment/Facilities

Frost formation, vibro-acoustic, pressure profile, and cold soak testing will be performed at Rockwell - Laboratories Test and Materials Science Department. Arcjet atmospheric entry heating simulation and wind tunnel tests will be performed at NASA -Ames.

3.7.6 Schedule

Begin search for TPS repair materials	1 April 1995
Repair techniques developed	30 August 1995
Test plan for repairs complete	30 September 1995*
Begin specimen fabrication	30 November 1995*
Arcjet testing (NASA-Ames)	June 1996
Wind tunnel testing	July 1996
Damaged/repaired TPS testing complete	30 August 1996*

* Formal Milestone

3.8 OTHER TESTING

Analysis performed under subtasks 3.1 and 3.2 will define the necessity, requirements, and methodologies of additional tests. These tests may include; 1) testing for the corrosive effects of salt air, 2) electrical discharge testing for lightning damage assessment, and 3) testing to evaluate the potential for

trapping O₂ and/or H₂ in the Velcro tile attachment interface, under development
in Task 4.

July 28, 1994

Development Test Plan 6450

Integrated Health Monitoring

NCC2--9003

TA-3

Task 6

Sub tasks 1 - 8

Task Leaders

Tom Gormley, SSD Rockwell

Anne Patterson-Hine, Ames NASA

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1.0 OBJECTIVE

1.1 The objective of this task is to identify cost-effective Integrated Health Management life cycle approaches for fault accommodation/detection, automated test and checkout, and status determination of the thermal protection system (TPS). Emphasis will be placed on optimizing robust TPS and sensor technologies that support wide-area and localized coverage, automation, remote sensing and maintenance-on-demand design to operation philosophies. Performance and maintainability envelopes for various TPS options will be determined by surveying existing TPS applications (Shuttle, DOD) and by characterizing the TPS materials (material properties, failure modes, functional environments, etc). Nondestructive Evaluation/Inspection (NDE) sensor technologies will be selected and functionally demonstrated based on expected failure modes and the technology capability to identify, locate, and quantify TPS system anomalies. The sensor technology information will be used to support the evaluation of TPS design alternatives and the development of the TPS/IHM systems for the 8 foot Reusable Hydrogen Cryogenic Tank System (TA1) and the Full Scale Wing Test Article (TA2) test programs at NASA-MSFC and NASA-LaRC, respectively.

1.2 The TPS/IHM will evaluate design alternatives, assembly and verification processes, establish inspection requirements, and identify NDE/NDI and IHM techniques for use on lightweight durable TPS. TPS/IHM will perform trades between more robust materials/designs and the capability of instrumentation and inspection techniques to determine system status and TPS degradation and failures within low cost operations goals.

1.3 The TPS/IHM task will also establish an electronic IHM database that will document the results of this test program; historical and current space rated TPS maintainability profiles; and will support future SSTO operational maintenance systems. These databases will include information on flight to flight performance of TPS and costs of maintenance (inspection, repair, replacement, refurbishment) and the fault analysis and decision algorithms that are used in estimating and scheduling of maintenance and inspection timelines and overall TPS operational readiness.

1.4 This development plan will follow an evolutionary path to the ultimate development of flight-quality systems. The developmental goals will be focused on maturing the recommended technologies to TRL 6 and to establish flight ready system design requirements.

2.0 BACKGROUND

2.1 TA3 (Lightweight Durable TPS) IHM TASK Plan is one of three IHM planned activities supporting the National Research Announcement 8-12 being worked by NASA AMES and Rockwell Space Systems Division at Downey. This development plan will establish tasks leading to TPS/IHM design and

system requirements and will develop test plans for IHM coupon/panel sensor characterization, and TPS/IHM system validation tests on the TA1 and TA2 test articles. This test plan will be updated throughout the program as required. A glossary of IHM/NDE Terms will be written and will be included as Appendix A to this document.

2.1.2 The primary goal of IHM for TPS (IHM/TPS) is to reduce the cost and time associated with pre-flight maintenance to a level where future SSTO operational turnaround is like that currently found in military aircraft. TPS maintenance will also be configured to avoid bottlenecking any work on the vehicle's other systems.

2.1.3 The most important factor in reducing TPS maintenance will be in the application of robust TPS materials while still meeting SSTO performance requirements. However, it is envisioned that robustness will at some point prohibit the SSTO from reaching its performance objectives. This is when operational health management concepts will have to be implemented. Even with robust TPS concepts, future SSTO's will experience TPS fatigue, failures, and damage during nominal operations over the vehicle's life cycle. Therefore, it is imperative to begin the development of a TPS/IHM system early in the design process in order to integrate IHM/TPS technology (sensors, software, etc.) into the SSTO system.

2.1.4 A comprehensive TPS/IHM system has both ground based monitoring and in-flight monitoring. Highly automated ground based monitoring and inspection supports maintenance on exception activities and is focused on insuring operational readiness while the in-flight monitoring is focused on these same objectives as well as gathering data on the life cycle exposure to assess long-term performance in an efficient manner. New promising NDE/NDI sensor and inspection technologies that are appropriate for both ground and in-flight monitoring will be examined under this NRA task agreement.

2.1.5 This TPS/IHM task is one of many activities being pursued by the TA3 Lightweight Durable TPS program. These other tasks will address key concerns on the durability of TPS surfaces, direct bonding of ceramic tiles, attachment schemes, adverse operating environments, and reusability. There will be test articles leading to the re-establishment of fluted-core flexible blankets, development of advanced flexible blankets that incorporate MLI, TPS bonded and mechanical attachments, and TPS robustness. These other TA3 tasks will be fully integrated with the TPS/IHM effort. The TPS/IHM Development Plan for TA-3 will provide:

- 1) NDE sensor screening process
- 2) Coupon level IHM Technology Demonstration
- 3) TPS IHM defect standards
- 4) Demonstration of TPS/IHM on a composite tank (8 ft.)
- 5) Demonstration of TPS/IHM on a Wing FSTA
- 6) Reporting

2.2 Schedule

<u>Milestone</u>	<u>Date</u>
IHM Sensors Screened	15 Oct. 94
IHM Defect Standards	30 Jun 95
IHM Approached Developed	30 Nov 95
IHM Demonstrated	30 April 96
IHM Report	30 Aug 96

2.3 Applicable Documents

"NRA8-12, Advanced Structures and TPS Technologies TA-3,
Lightweight Durable Thermal Protection System Proposal"

3.0 GENERAL REQUIREMENTS

The established policies and practices of the testing facility will dictate general requirements. If a particular test requires deviation from the performing test facility's requirements an exception must be established.

4.0 DETAILED REQUIREMENTS

The detailed requirements outlined below are by sub tasks.

4.1 IHM Integration & TPS Health Management Database

4.1.1. Requirement

Coordinate and provide IHM integration among NASA-ARC, MSFC, LaRC and SSD Team members. Provide integration between TA1, TA2 and TA3 NDE/IHM tasks as required.

4.1.1.a Estimated Completion Date: August 1996

4.1.1.b Task effort will run from May through August 1996

4.1.2 Approach

4.1.2.a. Integration will be accomplished in a variety of methods. Telecons will be conducted between AMES and SSD IHM personnel at a minimum twice a month or more frequently as required . Telecons will be conducted with TA-1 and TA-2 as required.

4.1.2.b. Face to face sessions will occur as deemed by either team member.

4.1.2.c IHM requirements will be provided to TA3 Engineers and Scientists. This will be done by attending design meetings and material & processing activities conducted by TA3 Engineers.

4.1.2.d. An IHM person will attend all program review meetings.

4.2 TPS Health Management Database

4.2.1 Requirement

4.2.1.a A database will be developed for TPS materials performance and failure mode information based on past experience with Shuttle operations. Additionally, laboratory and flight experiment data will be included, when available. The database will also incorporate information from the sensor and NDE survey and evaluation to be performed under this task. Experimental results from coupon, panel, tank, and wing structure tests will be included. The database will be used to cross-correlate detection mechanisms with failure modes. The costs for various detection strategies will be traded-off with the use of robust TPS materials.

4.2.1.b To begin the development of an TPS/IHM database and maximize its long-range benefits the lessons learned from current operational experience with Shuttle TPS materials will be used to establish investment strategies. A good understanding of the existing system and its strengths and weaknesses is necessary before recommendation of new sensor technologies, inspection techniques, maintenance strategies or fault tolerance philosophies can be explored.

4.2.1.c First, information on current Shuttle inspection, repair, refurbishment, and replacement procedures and costs will be used to construct a database which highlights today's capability and cost structure. This database will be used to assess the current Shuttle "IHM/TPS" program and judge the impact of robust materials, advanced inspection techniques, and NDE/NDI sensor and inspection technologies on TPS maintenance costs. Property information on TPS materials is available from the existing TPSX database.

4.2.2 Approach

4.2.2.a. Requirements for the database will be generated by Ames and Rockwell personnel. (7/94)

4.2.2.b Ames will survey COTS products based on the requirements for this task and one or more products will be procured for database prototyping. (7/94)

4.2.2.c. Data format definitions will be established to enable data transfer between Ames and Rockwell. (8/94)

4.2.2.d. Ames/SSD will define the database architecture. (9/94)

4.2.2.e Ames will populate the database with historical materials and flight data. (ongoing throughout program)

4.2.2.f. Ames/Rockwell will incorporate TA-3 experiment data. Rockwell will provide sensor and NDE data on diskette to Ames and Ames will incorporate the data into the database. Ames incorporate local experiment data, too. (data correlates to experiment dates)

4.2.2.g Rockwell will provide Ames the results of the sensor and NDE survey on diskette and Ames will incorporate that information into the database. (11/94)

4.2.2.h. Ames and Rockwell will identify costs associated with selected health monitoring strategies and the use of various TPS materials. Ames will incorporate this information into the database. Part of this data may come from the results of efforts found in task 3 of TA1. (date TBD)

4.2.2.i Ames will design and develop report formats which will summarize database information and allow trade-off to the performed such as costs for system testability vs. use of robust materials. (date TBD)

4.2 IHM Development Plan

4.2.1 Requirement

The development plan (this document) will identify the process to: develop IHM design and system requirements, identify system faults that will have to be monitored/managed during operations, predict/identify inspection plan requirements, and establish a preliminary test plan to be implemented during the Lightweight Durable TPS Program. The plan will identify preliminary TPS IHM plans for the 8 foot Composite tank test at MSFC and the Full Scale Test Article structural test at LaRC.

4.2.1.a Estimated Completion Date: 29 July 1994; with periodic updates.

4.2.1.b. Initial task effort will run from May through July 1994.

4.2.2 Approach

4.2.2.a The development plan will be written by AMES and SSD IHM personnel. This plan will outline tasks providing requirements, approaches and detailed test plans used on program hardware. This plan will be a dynamic document. Lessons learned during sensor selection will influence full scale test article testing and the 8 ft. tank testing at the end of this program. So, naturally test plans for the activities will be general early on and get more specific along the way.

4.3 Equipment and Sensor Screening

4.3.1 Requirement

TPS sensing technologies will be evaluated for both ground and in-flight application. Sensing and scanning technologies will be solicited from NASA/DOD, Aerospace and Commercial Industries. Evaluation criteria will be driven by system operational capability, sensor development cost, sensor operations costs/benefits, sensor maturity and availability.

4.3.1.a. Estimated Completion Date: October 1994

4.3.1.b. Task effort will run from June through October 1994

4.3.1.c. Reports and findings will be entered into the TPS Health Management Database.

4.3.2 Approach

Analysis and sensor technology screening will be performed on IHM integration and system analysis which will assist in the development of requirements. The sensors screening process shall be divided into different technologies bases - NDE Conventional and Advanced Sensor. To gather data for sensor comparisons and selection a Sensor Capability Classification Matrix will be developed. During the screening process institutions possessing sensor technologies will be explored. The Structural System Definition Statement will be used to assist in evaluating sensor capability. Representative coupons and panels, will be used in NDE sensor screening.

4.3.2.1 Sensor Technologies

4.3.2.1.a. Conventional are those NDE technologies that have available/established methods, techniques, off the shelf equipment and training materials. Examples are but not limited to; x-ray, ultrasonic, penetrant, magnetic particle, eddy current, helium leak detection, visual and microwave.

4.3.2.1.b. Advanced are those NDE technologies that build on the conventional NDE technologies and in some manner enhance the performance of the methods either generically or application specific. Examples are but not limited to; Laser Based Ultrasonic (LBU) Fiber Optics, Shearography, Computed Tomography and Thermography. Usually these are technologies that offer a unique approach or application of state-of-the-art technology.

4.3.2.2 Sensor Capability Classification Matrix

To assist in the weighing of each individual method a matrix will be developed to screen capabilities based on hardware requirements. This matrix is designed

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to help identify the most promising sensor technology. The matrix will be developed and documented during the sensor screening analysis.

4.3.2.3. Structural System Requirement Definition Statement

This statement will be generated through the TPS database analysis of failure modes and insulation/TPS integrity issues.

4.3.2.4. Sensor Technology Survey

4.3.2.4.a. A sensor technology solicitation will be conducted of NRA8-12 team players, Department of Defense, National Laboratories, aerospace and the commercial communities. This survey will respond to the Sensor Capability Classification Matrix criteria and the Structural System requirement Definition statement. Literary searches will be conducted to obtain a comprehensive collection of state-of-the-art NDE reports. This provides not only current background information but identifies key players in sensor application development. A literary bibliography will be maintained. Additionally, conferences will be attended or minutes obtain to gather the most current advances.

4.3.4. APPLICABLE DOCUMENTS

STS Structural Bond Review Report, dated July 19, 1989

Investigation Analyses of the RCC R/H Panel #10 Impact from STS 45 (OV-104)

4.4. Coupon Level IHM Technology Demonstrations

4.4.1 Requirements

Study the requirements for the selection of TPS IHM technologies on coupons and 4 foot Aluminum Tank with composite inserts for integrated system application. Evaluate sensor performance to non-intrusively determine the health of TPS structure and all TPS failure modes. (Through analysis specific failure modes will become identified for IHM monitoring.) Compare results against conventional NDE technologies. Preliminary tests will provide early insight into system requirements prior to panel level IHM characterization tests.

4.4.1.a. Estimated Completion Date: May 1995

4.4.1.b. Task effort will run from November 1994 through May 1995.

4.4.1.c. Reports and test results will be entered into the TPS Health Management Database.

4.4.2 Approach

4.4.2.1. Coupons Potential NDE sensors will be evaluated using fourteen (14) coupon level samples. These coupons will explore failure modes of TPS bonded to foam and TPS bonded to GR/Epoxy. Failure modes will be identified using the TPS Health Management Database. Failure modes agreed upon by Ames and Rockwell will be simulated on the coupons.

4.4.2.1.a. Panels will be IM7/977 material approximately .075" thick (nominally an 8-ply [0/±45/90]s layup or equivalent). The adhesives to be used to assemble the structure may change as the vehicle prototype design concept becomes more developed, but initial adhesive will be RTV 560 silicone adhesive for the tank structure. A "bumper" layer of Nextel cloth may be placed into the bondline between the TPS and foam layers. The purpose of the Nextel layer is to absorb and distribute impact loading when an incoming particle is encountered.

4.4.2.1.b. The TPS will include AAFRSI blankets (Rockwell configuration, fabricated per MA0605-3115), AETB tiles with TUFI coating, and FRXI insulation. The foam layer will consist of low-density (approximately 3.2 pct) Rohacell foam in a variety of depths ranging from 0.5 inches to 1.25 inches. The TPS thickness will range from 0.25 inches FRXI to 3.0 inches TUFI tiles.

4.4.2.1.2. A second evaluation phase will occur when a direct bond (no Rohacell Foam Insulation) of the TPS to the substructure is explored.

4.4.2.1.2.a Structure used in the direct bond task will be fabricated using graphite/bismalimide. Specimens requiring core will be bonded using American

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Cyanimides HT424 adhesive. All AETB tile will be bonded to the structure using General Electric's RTV 560 silicon adhesive with a nominal bond line thickness of 7-10 mils. 6x6" AETB-12 will be bonded to 8x10" substrate. 6x6" AETB-12 will be bonded to a 12x14" substrate. Specimens will be adhesively bonded using RTV 560 (MB0130-119 TYII) of bondline thickness from 10 to 20 mils and by the use of structural adhesive HT 424. AETB-12 tile with attached CMC cover will be direct bonded and bonded using .090" thick strain isolator pad.

4.4.2.1.2.b. Selected NDE sensor technology will evaluate the 15x40" seven tile array panel if available and applicable.

4.4.3 4 ft. Tank. SSD will use a four foot diameter aluminum cryogenic tank with a composite panel insert. This tank will be used as an early test bed for IHM system requirements and NDE sensor access and hardware configuration impacts. Insulation and TPS will be mounted on the exterior of the tank and then it will be loaded and unloaded with liquid nitrogen.

4.4.2.a. Test Objective

Establish preliminary TPS IHM sensor performance to monitor TPS failure modes.

4.4.2.b. Test Article Description

Coupons as described in 4.4.2.1 and an integrated sub scale (4 ft. diameter al.) cryogenic test article containing TPS and insulation. Damage other than preinduced flaws will be induced according to the test parameters in tasks 2, 4, and 5.

4.4.2.c. Test Description

Evaluate potential NDE sensors and selected IHM technologies in an integrated system environment during cryogenic loading and detanking tests.

4.4.2.d. Potential Instrumentation

Acoustic emission, ultrasonics, fiber optics, thermography, shearography, radiography.

4.4.2.e. Test Location

Rockwell SSD, Downey, California.

4.4.3 APPLICABLE DOCUMENTS

STS Structural Bond Review Report, dated July 19, 1989

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Investigation Analyses of the RCC R/H Panel #10 Impact from STS 45 (OV-104)

4.5. Test Article Defect Standards/IHM Approach

4.5.1 Requirements

Using the TPS Health Management Database (4.2) failure mode analysis, establish full scale test article defect requirements that need to be monitored and managed during the MSFC 8-ft Composite Tank and the LaRC Wing Structure FSTA tests. This effort will identify requirements to a lower level of detail than requirements identified in the IHM plan development, i.e., debond sizes to be monitored. The IHM system approach to accommodate these standards will be further refined based on preliminary IHM technology demonstrations on the 4 ft. cryogenic tank.

4.5.1.a. Estimated Completion Date: 6 December 1995

4.5.1.b. Task effort will run from November 1994 through November 1995

4.5.1.c. Reports and findings will be entered into the TPS Health Management Database.

4.5.2 Approach

TBD

4.5.3 APPLICABLE DOCUMENTS

STS Structural Bond Review Report, dated July 19, 1989

Investigation Analyses of the RCC R/H Panel #10 Impact from STS 45 (OV-104)

4.6. Eight Foot Diameter Composite Tank TPS IHM Demonstration

4.6.1 Requirement

This task first characterizes the preferred sensor technologies on an insulated composite panel with varying TPS options. Failure modes are intentionally introduced into the test specimens. This panel level effort will establish sensor performance to monitor TPS/failure modes, and impact damage assessment. The task then proceeds to integrate IHM requirements and the preferred technologies into the MSFC 8 ft. composite tank structural tests under cryogenic loading and detanking conditions to monitor failure modes and TPS integrity, cryopumping, and leakage.

4.6.1.a. Estimated Completion Date is June 1996.

4.6.1.b. Task effort will run from December 1995 through June 1996.

4.6.1.c. Reports and test results will be entered into the TPS Health Management Database.

4.6.2 Approach

4.6.2.1. The NDE technology used during the final demonstration of an integrated IHM system operating on the 8 ft. diameter tank will be demonstrated on a representative section of the tank. The NDE or sensor technology will have been previously screened and only the most promising technologies will be evaluated.

4.6.2.2. The test panel identified as IHM-1 under TA-1 will have the graphite/epoxy substructure and insulation/TPS mounted. This panel configuration will be an accurate representation of the tank. Pre-induced flaws will have been placed to represent failure modes for the Insulation and TPS attachment.

4.6.2.3. Finite element models will be used in the identification of flaws size and location of critical areas. These models will predict the outcome of the NDE test results which will improve scale up efforts, by providing sensor placement information, such as location, and sensor coverage for reliable IHM monitoring.

4.6.2.4. IHM-1 panel will be baselined using conventional NDE methods and the results will be correlated to selected sensor technologies used during testing of the panel. This panel will be tested under load. Successful sensors will be evaluated with IHM requirements and the 8 ft tanks operational requirements for applicability to monitoring of the tank.

4.6.2.1.a Test Objective

Characterize and verify sensor technology to detect TPS and Insulation failure modes and integrity.

4.6.2.1.b. Test Article Description

The panel's substructure will be manufactured under IHM activity in TA1. This panel has been identified as IHM-1. It is a 30 inch by 30 inch graphite/epoxy stiffened panel. Insulation and TPS selected by TA-3 Engineering will be mounted on IHM with pre-induced flaws (representing selected failure modes). This work will be accomplished at the SSD Downey Composite Laboratory.

4.6.2.1.c. Test Description

Characterize TPS IHM sensors.

4.6.2.1.d. Potential Instrumentation

Acoustic emission, ultrasonics, fiber optics, thermography, shearography, and laser based ultrasonics.

4.6.2.2. Eight Foot Composite Tank Insulation/TPS IHM Demonstration

4.6.2.2.a. Test Objective

Characterize and verify sensor technology performance on a graphite/epoxy composite tank with insulation and TPS for leakage during cryopumping, and selected failure modes for TPS/insulation under load.

4.6.2.2.b. Test Article Description

The TA-1 8 foot diameter composite tank with insulation and TPS.

4.6.2.2.c. Test Description

The IHM integrated system will be evaluated under cryogenic environment.

4.6.2.2.d. Potential Instrumentation

Only those sensors that can demonstrate the required sensitivity and resolution on the IHM--1 panel, can operate under the conditions required during testing, and can be successfully integrated into the IHM system will be used.

4.6.2.2.e. Test Location

MSFC

APPLICABLE DOCUMENTS

4.7.0 Wing/Aeroshell Full Scale Test Article (FSTA) TPS Demonstration

4.7.1 Requirement

Characterize the preferred sensor technologies on an insulated wing composite panel with varying TPS options. Flaws are intentionally introduced into the panel. Characterization results will establish sensor performance to monitor TPS/wing failure modes, and TPS integrity after impact damage. The task then proceeds to integrate IHM requirements and the sensor technologies into the LaRC Wing FSTA structural tests to monitor TPS integrity and disbonds.

4.7.1.a. Estimated Completion Date is August 1996.

4.7.1.b. Task effort will run from January 1996 through August 1996.

4.7.1.c. Reports and test results will be entered into the TPS Health Management Database.

4.7.2 Approach

4.7.2.a The NDE technology used during the final demonstration of an integrated IHM system operating on the TA2 FSTA wing will be demonstrated before hand on a representative section of the structure. The NDE technology applied will be the product of paragraph 4.3.

4.7.2.b. The test panel fabricated under TA-2 will have a graphite/epoxy substructure and TPS mounted to the external surface. This panel configuration will be an accurate representation. TPS failure modes will also be represented. Any flaws size requirements will come from TA-3 Engineering.

4.7.2.c. This test panel will be baselined using conventional NDE methods and the results will be correlated to advanced NDE sensors used during testing of the panel. This panel will be test under load. Successful sensors will be evaluated with IHM requirements and the FSTA's operational requirements for applicability to monitor the wing during testing.

4.7.2.1.a Test Objective

Characterize and verify selected sensor technology to detect wing panel TPS failure modes and TPS conditions at panel level.

4.7.2.1.b. Test Article Description

The substructure will be fabricated under TA-2 IHM activities. This panel will be approximately 18" by 36" with various TPS options attached.

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4.7.2.1.c. Test Description

The panel will be loaded to simulate flight conditions. Sensors will be evaluated during loading to characterize the TPS IHM potential.

4.7.2.1.d. Potential Instrumentation

Acoustic emission, ultrasonic, fiber optics, thermography, shearography, and others.

APPLICABLE DOCUMENTS

STS Structural Bond Review Report, dated July 19, 1989

Investigation Analyses of the RCC R/H Panel #10 Impact from STS 45 (OV-104)

4.7.2.2. FSTA IHM Demonstration

4.7.2.2.a Test Objective

Characterize and verify under test conditions sensor technology on the FSTA wing with TPS attached.

4.7.2.2.b Test Article Description

The TA-2 Full Scale Test Article with TPS and NDE sensors.

4.7.2.2.c Test Description

The IHM integrated system will be evaluated under loaded conditions.

4.7.2.2.d Potential Instrumentation

Only those sensors that can demonstrate the required sensitivity and resolution on the wing panel, can operate under the conditions required during testing, and can be successfully integrated into the IHM system will be used.

4.7.2.2.e Test Location

LaRC

APPLICABLE DOCUMENTS

STS Structural Bond Review Report, dated July 19, 1989

Investigation Analyses of the RCC R/H Panel #10 Impact from STS 45 (OV-104)

4.8. IHM Reporting

4.8.1 Requirement

4.8.1.a. Finalize IHM Program documentation, test results, lessons learned and recommendations for further efforts.

4.8.1.b. Updated versions of the TPS Health Management Database will be furnished at reporting dates.

4.8.1.c. Reports will be entered into the TPS Health Management Database.

4.8.2 Approach

Quarterly and the final report will be the efforts of both AMES and SSD. SSD will have primary responsibility.

APPENDICES

Appendix A, Arcjet facilities, 60 and 20 MW	DTP 6451-810
Appendix B, Wind tunnel	DTP 6451-811
Appendix C, Debris impact	DTP 6451-812
Appendix D, Rain impact	DTP 6451-813
Appendix E, Rain impact, single drop	DTP 6451-814
Appendix F, Rain/wind	DTP 6451-815
Appendix G, Salt Spray	DTP 6451-816
Appendix H, Vibroacoustics	DTP 6451-817
Appendix I, Vibration	DTP 6451-818
Appendix J, Radiant exposure	DTP 6451-819
Appendix K, Venting	DTP 6451-820
Appendix L, Air Impingement	DTP 6451-822

APPENDIX A

ARCJET TESTING

**PLASMA ARC
DETAILED TEST PROCEDURE
NRA 8-12, SSTO TA-3**

INTRODUCTION:

This Detailed Test Procedure (DTP) defines the plasma arc exposure testing for the TPS material developed in the different tasks of TA3. The specimen material, size and configuration will be specified by each task. The plasma arc tests will be performed at the NASA/AMES plasma test facilities. There are several different facilities including the Aerodynamic Heating Facility (20 MW), the Interaction Heating Facility (60 MW), the Panel Test Facility (20 MW), and the Turbulent Flow Duct (20 MW). Each facility has its unique capabilities in simulating different heating environments to test different types of test articles.

TEST OBJECTIVE

To evaluate the temperature capability, surface durability and backface temperature of the TPS materials in the simulated aerodynamic heating environment of the plasma arc test. Thermal conductivity and catalysis will be determined by the temperature data and re-radiative heat flux measurements obtained in the test. A secondary objective is to correlate experimental data with thermal and computer generated thermal models.

SCOPE

This document describes testing of each task and is limited to those tests. The actual facility operations and related procedures will be the responsibility of NASA/AMES. Changes to this plan which are in the scope of the test request may be made by "Redline" changes approved by the Responsible Test Engineer, and documented in the Laboratory Notebook.

APPLICABLE DOCUMENTS

- Ames Research Center - Arc Jet Testing Guide
- Quality Assurance Specification and Quality Requirements for off site test, MT0802-105A
- The Laboratory & Test (L&T) administrative document : Laboratory Request (LR)
- Rockwell Laboratory notebook for recording observations during testing.
- NASA Ames specification "9SP-9001-XR5, Thermocouple Probe Fabrication and Installation Procedure for Flexible Insulation"

GENERAL REQUIREMENTS

Handling of test panels

When handling the test panels or any part of the test specimen assembly clean white cotton gloves or equivalent shall be worn to prevent contamination. Any specimen physical damage such as accidental surface contamination will be documented in the Laboratory Notebook by the Responsible Test Engineer (RTE).

When handling SiC fibers, Neoprene type (Edmont, Sol-Vex #37-145 or equivalent) gloves should be worn. All precautions indicated in the Material Safety Data Sheet (MSDS) for the SiC fibers should be carefully followed. After thermal exposure of the SiC test articles, take caution to prevent dispersion of fibers.

Notice of Test

The RTE shall be notified in advance of any scheduled test.

Photographic Coverage

Color photographs will be taken of the test panels when any visual variance from initial condition is noticed.

Inspection

A general visual inspection of the test panel and fixture shall be made prior to the start of the test. A complete visual inspection along with color photographs shall be made after each test in order to determine any damage that might occur.

Report

The test agency shall provide all test data to the RTE. The RTE shall be responsible for publishing a Laboratory Test Report (LTR). The technical content of the LTR shall be the responsibility both the test agency and the RTE.

TEST SPECIMEN PREPARATION

The material specimen fabrication, instrumentation and assembly shall be by Rockwell to the requirements and procedures to be defined in each of the tasks. The test will

A test configuration found in an AFRSI certification report (Panel Test Facility, 20 MW) is used as an example in this DTP (See Fig. 1 - 5). Modification will be made according to the requirements of each task.

For testing to be conducted at the Panel Test Facility, aluminum plates (6061 - T6) can be fabricated as carrier plates. Plates with appropriate dimensions (to be defined by each task) shall be cut, etched per MA0110-305 and primed per MA0608-301 code 00-AA-21-XX.

Specimen shall be bonded to the aluminum plates per MA0 606-317. .

TEST PANEL INSTRUMENTATION

Appropriate number and type of thermocouples for the required temperature range will be instrumented in the specimens to the requirements of each different task.

Appropriate control articles with known thermal properties will be utilized (e.g. FRCI tiles) as reference and for calibration purposes. Thermocouples will be instrumented in the control articles accordingly. The locations of the instrumentation is TBD for each task. NASA Ames specification "9SP-9001-XR5, Thermocouple Probe Fabrication and Installation Procedure for Flexible Insulation" will be used as a guideline.

TEST SETUP DESCRIPTION

The plasma exposure will be conducted at NASA Ames test facilities. The facility, specimen and sample holder configurations, and test parameters are TBD according to the purposes of the testing of the task.

Rockwell will assemble the specimen and instrumentation to conform to NASA Ames test fixture configuration. For the Panel Test Facility specimen configuration, in some instances, a cooling plate will be used on the back surface of the test panel to limit the bondline (IML) temperatures to a maximum of 350°F. In other instances, adiabatic back wall might be necessary. The exposed portion of the test specimen aluminum carrier plate shall be closed out using glasrock or other rigid RSI.

TEST PROCEDURE

NASA/Ames shall provide the facility apparatus, setup, data acquisition, data reduction and facility procedures for plasma exposure.

Test Conditions

The OML surface of the specimens shall be exposed to a heating environment and duration time defined in the test matrix (See Table I as an example) which is TBD for each task resulting in the control article surface temperature to be defined for the particular type of control article material at minimum attainable chamber pressure. Thermocouple will be instrumented at the backface of the test specimen to monitor the temperature there. For the Panel Test Facility, maximum soak and temperature on the IML shall be limited to 350°F by use of a coldplate or other technique chosen by the test agency and approved by the RTE. An optical pyrometer shall be used to monitor the surface temperature of the blankets (approximately 2 microns narrow band sensor for best results). The pyrometer data acquisition shall be non-interference with the plasma test exposures.

Routine test procedures shall be the responsibility of the testing agency (NASA/Ames).

Pre-test Calibration

The test environment of NASA/Ames 20 MW and 60 MW plasma arc facilities shall be demonstrated by a series of runs using the control article (provided by Rockwell) calibration model instrumented with appropriate type of thermocouples.

Test specimens shall be visually inspected before insertion into the test chamber. After specimens are in the test chamber, verify all components are properly fitted.

After calibrations are made each test specimen shall be placed in the test fixture holder and exposed thermally to plasma flow as indicated in the test matrix.

Prior to starting a test run the thermocouples shall be reading properly at ambient temperature and the test instrumentation shall be checked for continuity.

All data shall be recorded at specified TBD sampling rate. Test data shall be recorded on any medium per facility capability. The tabulated engineering data, temperature, pressures and time parameters shall be furnished by NASA/Ames to the RTE at the completion of each test run.

TEST ARTICLE DISPOSITION

At the completion of the test the test specimens shall be returned to Rockwell, Space Systems Division, Laboratories and Test, Dept. 284 for retention.

Table I - Sample Test Matrix

Specimen ID/batting	Thermal Exposure	Duration
Tyranno TABI/Saffil	1500F	17 min
Tyranno TABI/Saffil	2000F	17 min
Tyranno TABI/440	1500F	17 min
Tyranno TABI/440	2000F	17 min

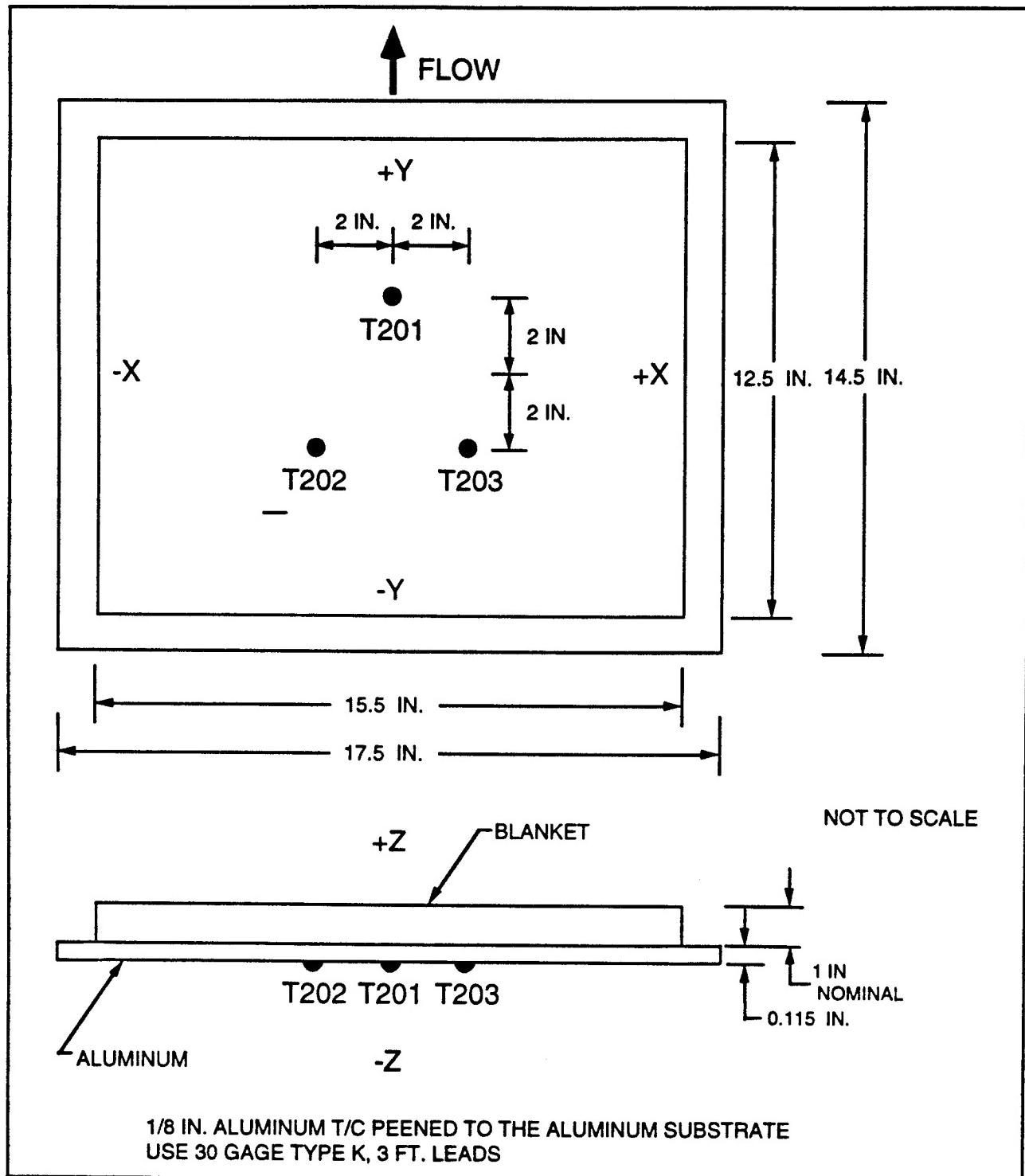


FIGURE 1

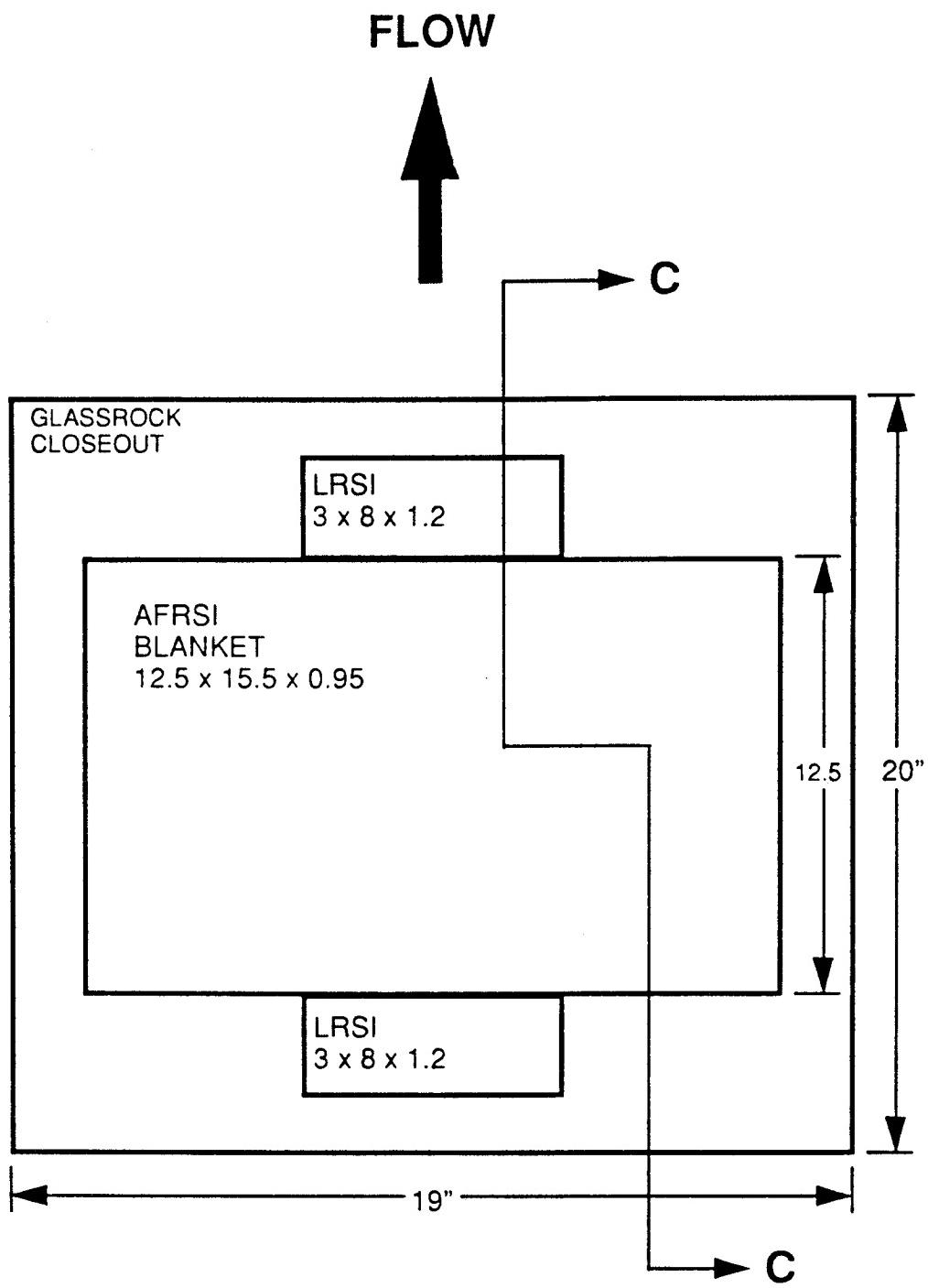


FIGURE 2

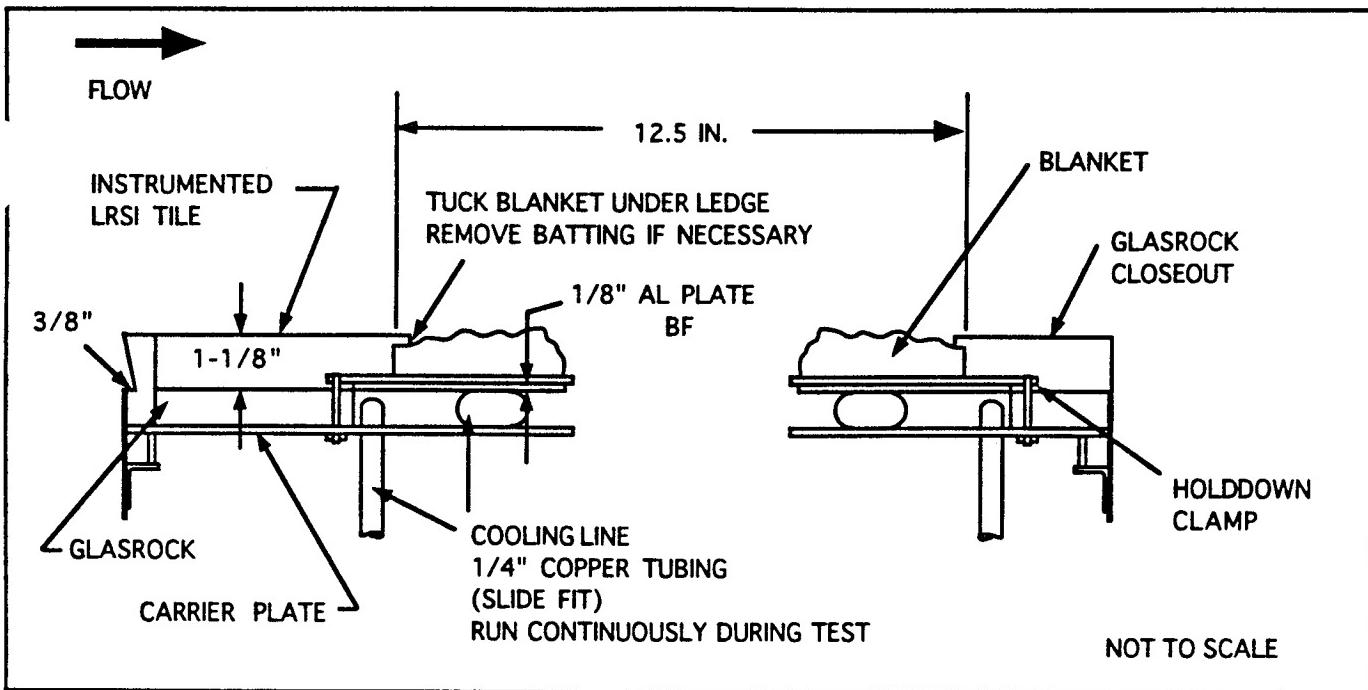


FIGURE 3

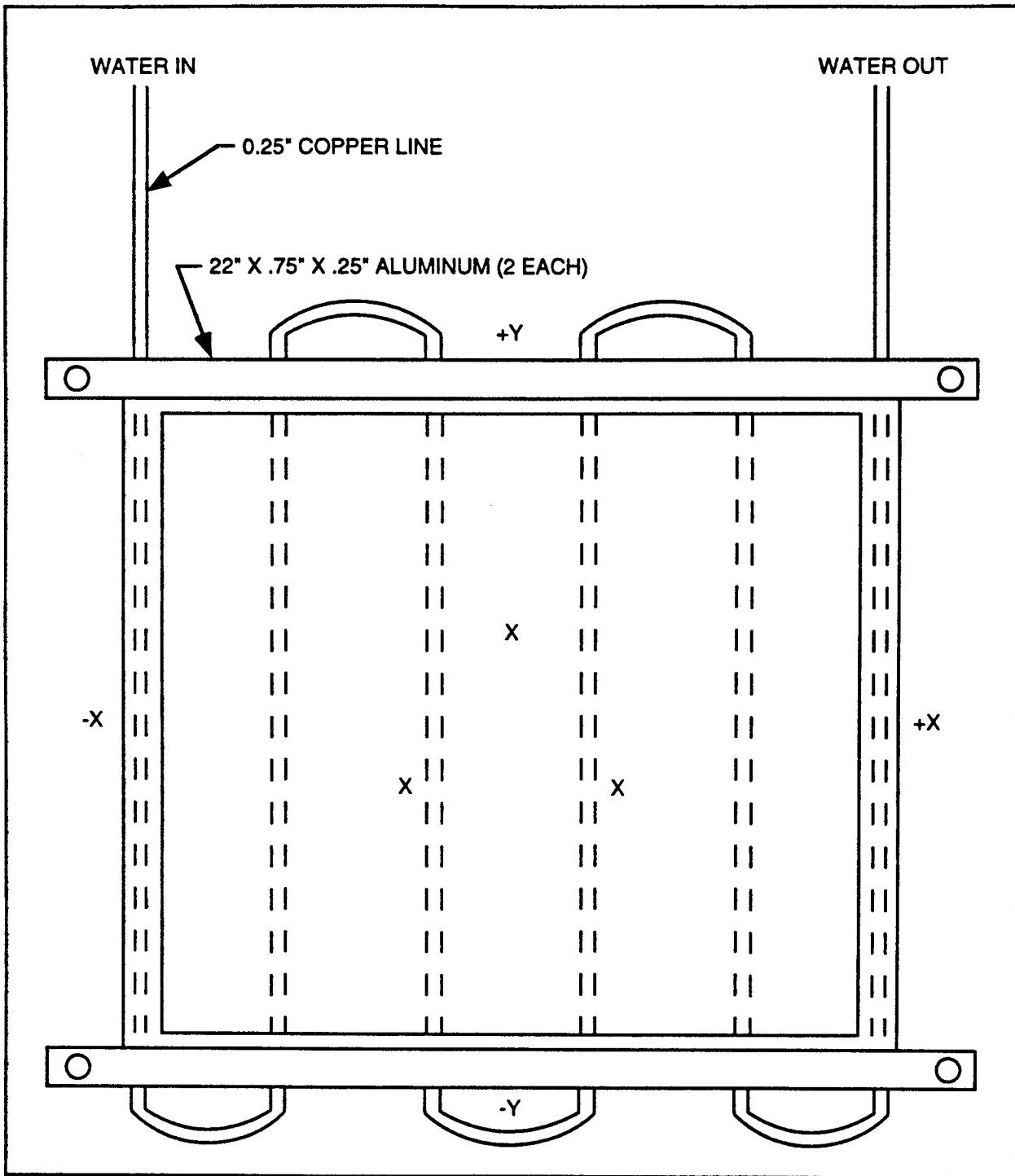


FIGURE 4

BACKFACE

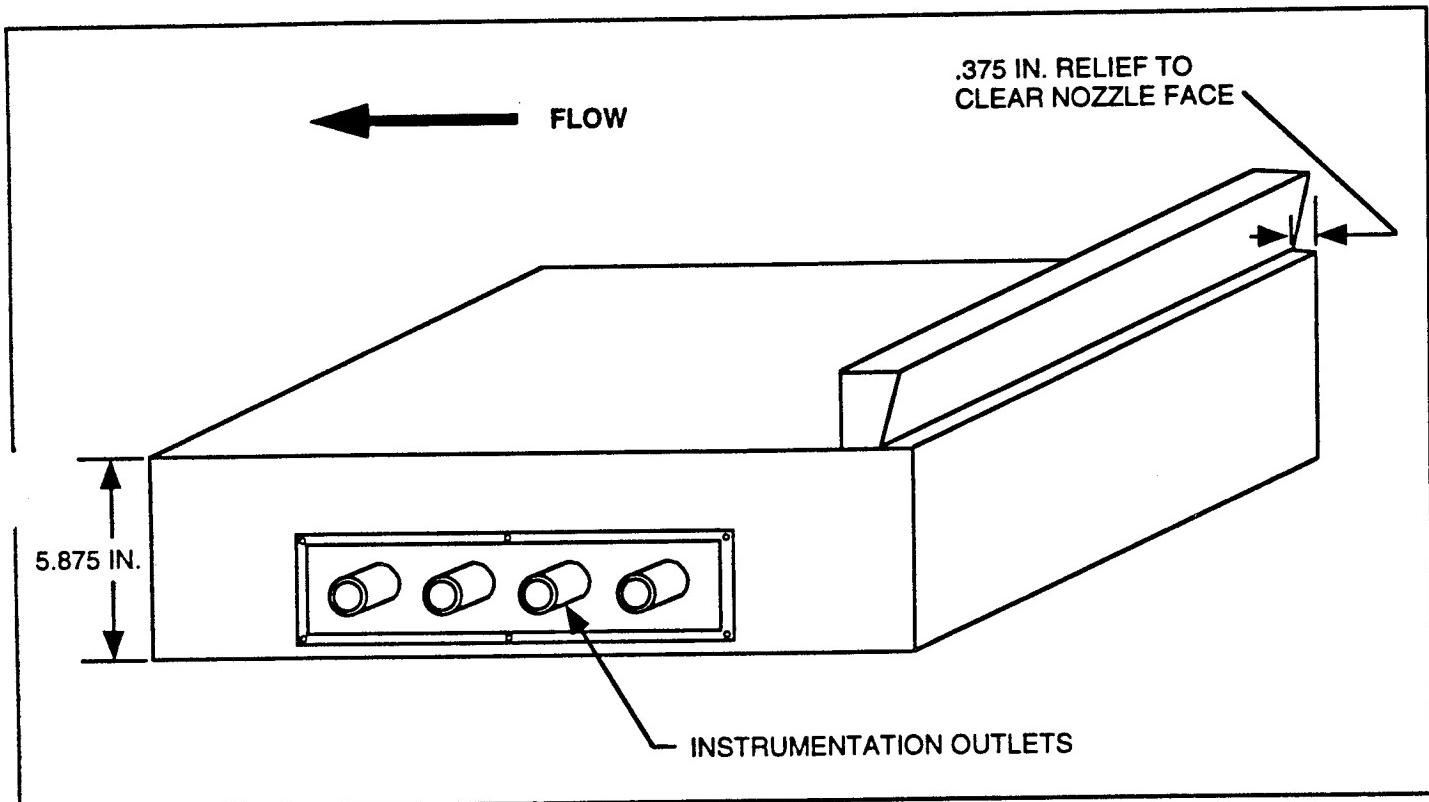


FIGURE 5

APPENDIX B

WIND TUNNEL TESTING

**Wind Tunnel Testing of TPS Materials
Detailed Test Plan
SSTO/Access to Space NRA 8-12**

**Cooperative Agreement NCC2-9003
TA-3 Light Weight Durable TPS**

prepared by:

David Wittman
Rockwell SSD

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1.0 Objective

The objective of this test program will be to generate data for a variety of Thermal Protection System (TPS) materials when exposed to anticipated flight wind conditions for the proposed SSTO vehicle.

2.0 Background

The Rockwell SSTO baseline vehicle currently utilizes a composite hydrogen tank with externally-bonded Rohacell foam and with TPS materials bonded to the outer surface of the foam. There may also be a "bumper layer" of Nextel cloth between the TPS and the foam, depending upon test results and upon later trade studies and design requirements to be generated by the prototype design team.

3.0 General Requirements

3.1 Documentation

The following forms of documentation will be utilized for this program (and all programs to be conducted as part of the SSTO NRAs in work at Rockwell):

3.1.1 Detailed Test Plan

All testing will be conducted in accordance with this detailed test procedure.

3.1.2 Laboratory Notebook

A laboratory notebook will be maintained by the Rockwell Responsible Test Engineer (RTE), depicting a complete test history. Test article configuration, instrumentation, test anomalies and all other pertinent data and information will be recorded in the notebook.

3.1.3 Test Report

The test agency will issue a Laboratory Test Report (LTR). The LTR will depict the complete test program, instrumentation, test procedures and results, test setup, photographs, test data, and any other pertinent information relating to the test.

3.2 Instrumentation

All measurement instrumentation shall be calibrated and have a decal showing a valid calibration due date. A list of all test instrumentation will be maintained in the Laboratory Notebook.

3.3 General Requirements for Wind Tunnel Testing

The specific task leader at Rockwell will provide environmental parameters the the NASA-Ames facility contact for operation of the chosen wind tunnel facility, along with dates and duration required.

3.4 General Flow of Work

Specimens will be prepared by Rockwell-SSD and shipped to NASA-Ames for wind tunnel exposure. The tested specimens/panels will then be returned to Rockwell-SSD for final evaluation and documentation of results, and a test report will be issued by Rockwell.

4.0 Applicable Documents

SS-A01999, Test Panel Details and Installation, 81-0 Model Test Fixture,
(Rockwell Drawing)

Cooperative Agreement NCC2-9003, TA-3 Lightweight Durable TPS

5.0 Detailed Requirements

Detailed requirements will be provided by the detailed test plan for the particular task. The key parameters to be specified are:

- Wind Tunnel to be used (Unitary or small tunnel)
 - which leg of Unitary : subsonic, transsonic, or supersonic
- location of TPS (and associated wind environment)
- vehicle mission parameters (trajectory, max Q-alpha, etc)
- temperature & pressure profiles to be applied
- Number of channels of data to be acquired or monitored, including
 - thermocouples
 - pressure transducers
 - other instrumentation (e.g. IHM sensors TBD)
 - facility data or data tags such as time, pressure, mach numbers, temperature, etc.

6.0 Detailed Test Specimen Description

Test specimens for the Unitary Wind Tunnel will be fabricated per Rockwell drawing SS-A01999 to be compatible with the Model 81-0 Test Fixture. This specimen is a rectangular flat panel, approximately 40x27 inches including the mounting frame.

7.0 Test Procedure

Testing will be performed using standard operating procedures for each respective wind tunnel facility, using specified parameters TBD. All test panels will be fabricated and instrumented by Rockwell and shipped to NASA-Ames for testing. Test facility operators will be provided by NASA-Ames, to be coordinated by Sal Riccitello (415) 604-6080 or Mike Green (415) 604-5595.

8.0 Sample Data Sheets

Data sheets will include location of pressure transducers and thermocouples, operating parameters used for the tunnel facility, and specimen identification. The data sheets will also include a location for observed behavior during and after the wind exposures.

9.0 Test Equipment

Wind Tunnel testing will be performed in the 9x7-foot NASA Ames Unitary Wind Tunnel, using both the transsonic and supersonic legs, as well as in a smaller 2x2 wind tunnel, depending upon individual test program requirements.

10.0 Sketches and Schematics

11.0 Schedule

Testing will be scheduled as required by specific task leaders, with the relevant NASA-Ames personnel.

Note:

The Unitary Wind Tunnel is currently undergoing a major refurbishment and overhaul and will not be available for test until June 1995. The small tunnel is available for immediate use.

First Planned Use of Unitary Wind Tunnel: July 1995 (Task 5)

APPENDIX C

DEBRIS IMPACT TESTING

**DEBRIS IMPACT TESTING
DETAILED TEST PROCEDURE
NRA 8-12, SSTO TA-3**

OBJECTIVE:

The objective of this testing is to determine the damage sustained by TPS materials from solid particle impact of typical sizes, densities and velocities characteristic of low earth orbit.

SCOPE:

This document describes standard hypervelocity impact testing to be accomplished at the NASA-Ames light gas gun facility. Specific test requirements are contained in the referencing document.

APPLICABLE DOCUMENTS:

TEST SPECIMEN PREPARATION:

Test specimens shall be prepared as described in the referencing document. The NASA-Ames test facility chamber can accommodate specimens up to approximately 18 x 18 inches.

TEST SPECIMEN INSTRUMENTATION:

No specimen instrumentation is required.

TEST METHOD DESCRIPTION:

Hypervelocity impact testing at NASA-Ames utilizes a standard light gas gun apparatus to accelerate particles to velocities up to nearly 8 km/sec. A brief description of the operation of a light gas gun follows.

A powder charge accelerates a piston, compressing H₂ gas in the first stage of a light gas gun. At a predetermined pressure, a restraining disk bursts and the compressed H₂ gas expands into the evacuated second stage which contains a sabot which holds the projectile. The sabot and projectile are accelerated down the second stage barrel where they enter the impact chamber. The sabot is

stripped away from the projectile and stopped by an aperture and finally the projectile impacts the target. Projectile velocity is typically calculated from a photographic record immediately before impact.

GENERAL REQUIREMENTS:

1. All testing shall be performed using a witness plate behind the test specimen in order to characterize impacts that cause through damage.
2. Witness plates shall be 0.25" 2024-T0 Aluminum or similar.

PROCEDURE:

All standard procedures established by NASA-Ames facility personnel will be followed throughout this test effort.

Each impact test shall be defined by establishment of specimen type, impact velocity, impact angle, projectile density, and projectile diameter. These quantities are contained in the referencing document.

DATA REQUIREMENTS:

Standard characterization of hypervelocity impact damage shall be performed. This includes physical measurements of specimen damage as well as relevant measurements to witness plates. A photographic record of impact damage shall also be made. Projectile mass, diameter, density, and impact angle shall be recorded.

A copy of all data shall be transmitted to the responsible test engineer.

TEST ARTICLE DISPOSITION:

Test articles shall be returned to the Rockwell responsible test engineer for retention.

APPENDIX D

RAIN IMPACT TESTING

**RAIN IMPACT (ROTATING ARM)
DETAILED TEST PROCEDURE
NRA 8-12, SSTO TA-3**

OBJECTIVE:

The objective of this test is to determine the effects of rain impacts at high velocities on TPS materials. Test impact velocities shall simulate those characteristic of launch/landing.

SCOPE:

This document describes standard rotating arm testing to be accomplished at Wright Laboratories/Materials Directorate, Wright-Patterson Air Force Base. Specific requirements are discussed in the referencing document.

APPLICABLE DOCUMENTS:

"Utilization Policies, Operating Procedures and Specimen Configurations", Revision 4, June 1992. University of Dayton Research Institute, Dayton, OH.

TEST SPECIMEN PREPARATION:

The rotating arm facility requires that pairs of identical specimen be tested simultaneously. The maximum allowable weight differential between specimen is 2.0 grams. Test specimen preparation will be accomplished as described in the referencing document and as required in Applicable Documents - (1).

Typical specimen dimensions for 45° and 90° impact testing are shown in Figure 2 and 1. The facility has holders to accommodate other specimen sizes (see applicable document - (1)). If necessary custom holders can be machined.

TEST SPECIMEN INSTRUMENTATION:

No specimen instrumentation is required.

TEST SETUP DESCRIPTION:

The Wright Labs Rain erosion facility is shown schematically in Figure 3. It consists of a balanced arm which rotates about a vertical axis. Specimens are mounted at the arm tips where they are driven to velocities of between 0 and 650 mph. A calibrated 1 inch per hour rainfall is produced from 100 capillaries situated above the circular path traveled by the test specimen. Test specimens are normally subjected to the rain field at a given velocity for a predetermined

time, or until visible damage has been sustained. The test specimens are continuously monitored by video during the entire test procedure.

GENERAL REQUIREMENTS:

1. Test specimens must be received by the test facility at least seven days prior to the scheduled testing date.
2. Detailed descriptions of all test specimens must be delivered to the test facility with the test specimens.

PROCEDURE:

Paired test specimens shall be exposed to the calibrated rain field at the impact angle, velocity, and time duration stipulated in the referencing document. All standard test procedures of the Wright Laboratories/Materials Directorate Rain Erosion Facility shall be utilized during testing.

DATA REQUIREMENTS:

Specific damage and failure modes such as surface abrasion, pitting, cracking, cratering, etc., shall be recorded of all test specimens. A detailed description of the visual state of the test specimens shall also be documented.

A photographic record shall be made of all specimens prior to and after testing.

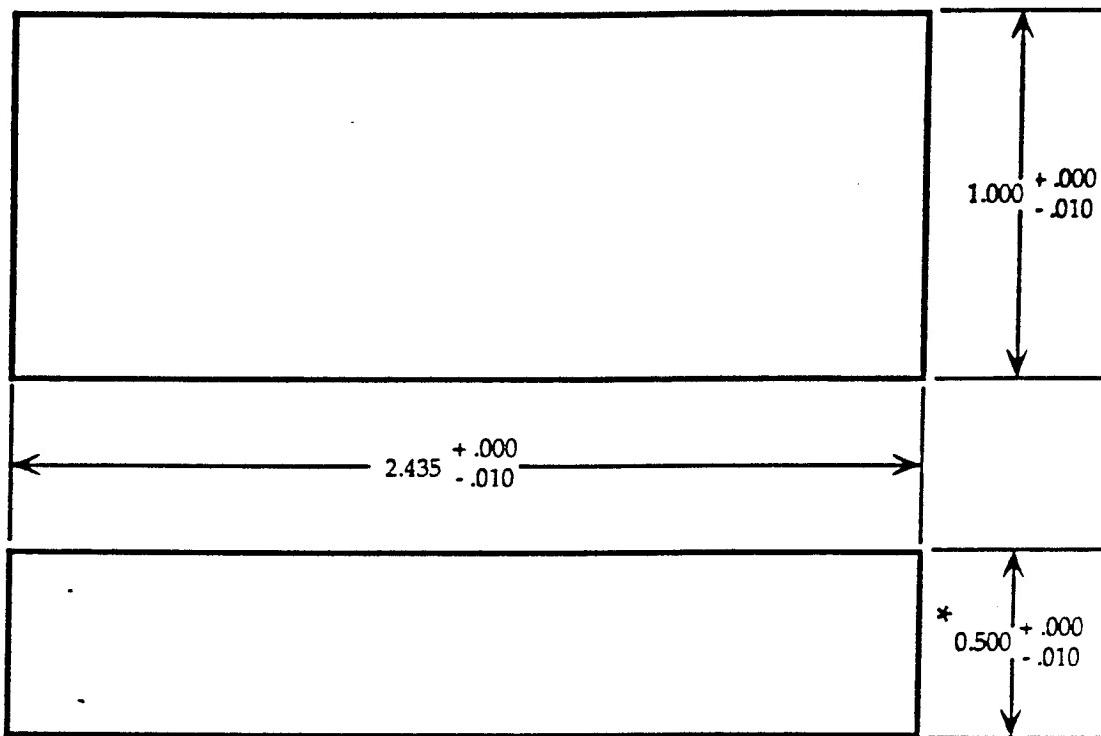
Mass loss of the specimens shall be recorded.

All data shall be delivered to the test requester and responsible test engineer or their representative.

TEST ARTICLE DISPOSITION:

Test articles shall be returned to the Rockwell responsible test engineer for retention.

90° SPECIMEN - CONFIGURATION 2



ALL DIMENSIONS IN INCHES

TOTAL DIMENSIONS INCLUDE ANY APPLIED COATINGS

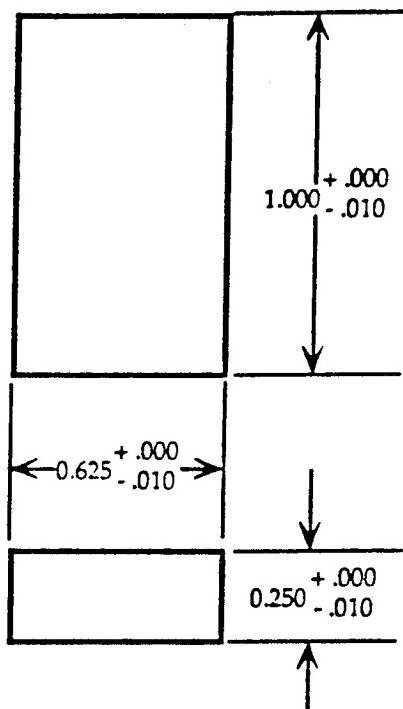
- * Specimens can be any thickness from 0.125 to a maximum of 0.500.

Any thickness under 0.500 must have shims supplied for both specimens for a total mounting thickness of 0.500

Maximum weight of specimen is 190 grams.

Figure 1. Specimen dimensions for 90° impact angle

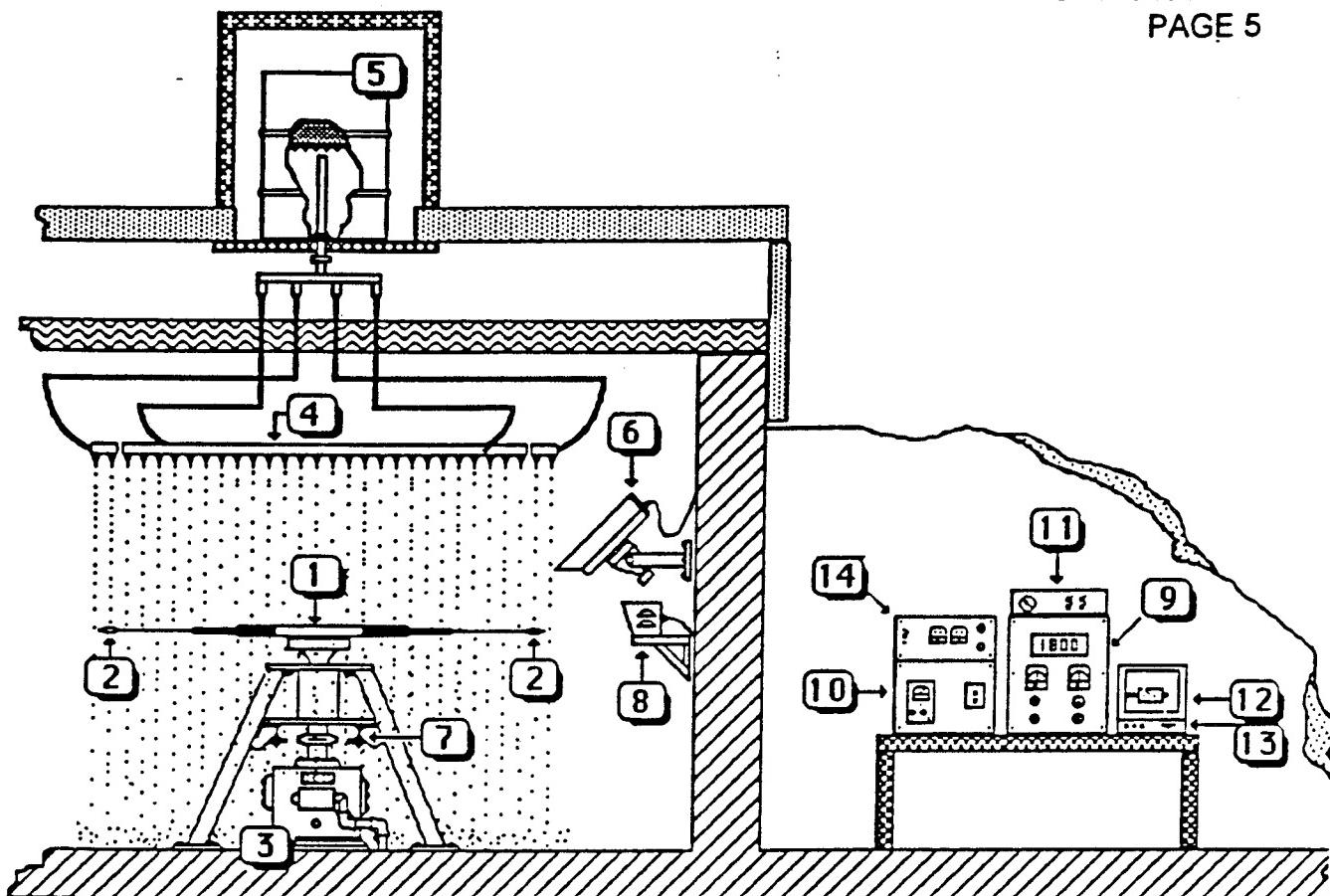
45° SPECIMEN - CONFIGURATION 2



ALL DIMENSIONS IN INCHES

TOTAL DIMENSIONS INCLUDE ANY APPLIED COATINGS

Figure 2. Specimen dimensions for 45° impact angle



1. DOUBLE ARM BLADE
2. MATED TEST SPECIMENS
3. VERTICAL DRIVE GEAR BOX AND SHAFT
4. CURVED MANIFOLD QUADRANT
5. WATER STORAGE TANK FOR RAIN SIMULATION
6. REMOTE CONTROLLED CAMERA
7. MAGNETIC PICK-UPS FOR FIRING THE STROBE
8. HIGH INTENSITY STROBE LIGHT FOR STOP MOTION VIEWING
9. VARIABLE SPEED READOUT AND CONTROL
10. STROBE CONTROL FOR SPECIMEN SELECTION
11. REMOTE COLOR CAMERA CONTROL
12. COLOR MONITOR FOR SPECIMEN VIEWING
13. VCR FOR VIDEO TAPING TESTS
14. RAIN SIMULATION CONTROL

Figure 3. Schematic of the WL/MD rain erosion facility

APPENDIX E

RAIN IMPACT, SINGLE DROP TESTING

**RAIN IMPACT (SINGLE DROP IMPACTS)
DETAILED TEST PROCEDURE
NRA 8-12, SSTO TA-3**

OBJECTIVE:

The objective of this test is to determine the effects of rain and/or ice impacts at high velocities on TPS materials. Test impact velocities shall simulate those characteristic of launch/landing.

SCOPE:

This document describes standard single-drop impact testing to be accomplished on the 30 mm powder gun at the Advanced Technologies Division of General Research Corporation. Specific detailed test requirements are discussed in the referencing document.

APPLICABLE DOCUMENTS:

"Capabilities Summary: Dynamic Behavior of Materials and Structures", February 1993, General Research Corporation, Santa Barbara.

TEST SPECIMEN:

The 30 mm powder gun used for single drop impact testing can currently accommodate specimens up to 0.788 inches in diameter. A cylindrical "sabot" is used to hold the sample and together they are accelerated through the gun's barrel. Normal incidence impacts are accomplished by utilizing a cylindrical specimen with its face perpendicular to its axis. Off normal impacts can be achieved by changing the axis/face angle appropriately. Non-circular cross section specimens of face dimensions less than 0.788 inches and a wide range of thicknesses can also be used. A detailed description of the test articles is contained in the referencing document.

TEST SPECIMEN INSTRUMENTATION:

No specimen instrumentation is required.

TEST SETUP DESCRIPTION:

The General Research drop impact facility is shown schematically in Figure 1. It consists of a 30 mm barrel, a test chamber, and a recovery chamber. A powder charge accelerates a sabot and sample down the barrel into the test chamber

where it collides with a single water drop. After collision, the sabot is decelerated to a stop in the recovery chamber. A laser optic system is used to control timing and to measure sample velocity before impact. A high speed camera is used to document drop or ice particle size and shape.

GENERAL REQUIREMENTS:

1. Test specimen must be received by the test facility at least seven days prior to the scheduled testing date.
2. Detailed descriptions of all test specimen must be delivered to the test facility with the test specimen.

PROCEDURE:

Test specimens shall be exposed to single drops at the impact angle and velocity stipulated in the referencing document. All standard test procedures of the General Research Rain Erosion Facility shall be utilized during testing.

DATA REQUIREMENTS:

Specific damage and failure modes shall be recorded of all test specimens. A detailed description of the visual state of the test specimen shall also be documented.

A photographic record shall be made of all specimens prior to and after each impact.

Mass loss of the specimen shall be recorded.

All data shall be delivered to the test requester and/or responsible test engineer.

TEST ARTICLE DISPOSITION:

Test articles shall be returned to the Rockwell responsible test engineer for retention.

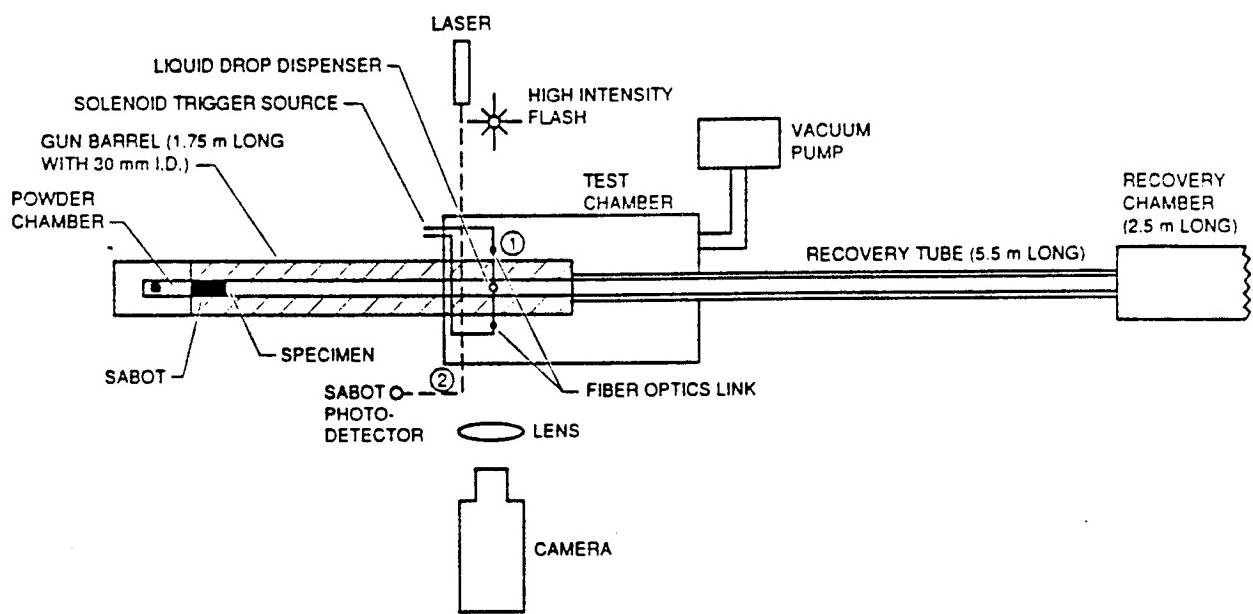


Figure 1. Schematic of the General Research Rain Erosion Test Facility

APPENDIX F

WIND/RAIN TESTING

WIND/RAIN
DTP 6451-815
PAGE 1

**WIND/RAIN EXPOSURE
LABORATORIES AND TEST
DETAILED TEST PROCEDURE
NRA 8-12, SSTO TA-3**

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1.0 INTRODUCTION

This document lists rain/wind requirements for SSTO lightweight durable TPS, NRA 8-12.

2.0 PURPOSE

The purpose of the wind/rain testing is to expose SSTO configurations to representative launch pad/landing facility conditions to verify durability in such adverse environments.

3.0 APPLICABLE DOCUMENTS

- 3.1 GOP 3841-001 Space Systems Division, Laboratories and Test, General Operating Procedure for Rain/Wind Test Facility.

4.0 GENERAL REQUIREMENTS

4.1 Test Data

- 4.1.1 Test data shall be recorded on data sheets approved by the RTE, and retained in the test program permanent data file.
- 4.1.2 All pertinent events, test conditions and test results shall be recorded in Laboratory Notebooks.
- 4.1.3 Copies of the Laboratory Notebook pages shall be transmitted to the Responsible Test Engineer (RTE) at the conclusion of the tests.
- 4.1.4 All test information accumulated in the form of data sheets, plots, or charts shall be transmitted to the RTE.
- 4.1.5 Photographs shall be taken at appropriate times to document test setups and anomalies encountered.

4.2 Notice of Test

- 4.2.1 The RTE and Engineering Coordinator shall be notified at least 24 hours prior to start of test.

4.3 Anomaly Reporting

- 4.3.1 The RTE and Engineering Coordinator shall be notified immediately in the event of an anomaly.
- 4.3.2 L&T management shall be notified in accordance with L&T Administrative Letter (AL) 20.
- 4.3.3 Trouble shooting shall be performed in accordance with planned steps documented in the lab notebook and approved by the RTE.

4.4 Test Reporting

- 4.4.1 A formal LTR is not required as contract documentation. Copies of the Laboratory Notebook pages shall be transmitted to the RTE.

5.0 DETAILED TEST REQUIREMENTS

5.1 Test Equipment and Instrumentation

- 5.1.1 A list of all test equipment and instrumentation will be maintained in a Laboratory Notebook. The list will show the item name/description, metrology number and calibration due date.
- 5.1.2 All measurement instrumentation (except standard rain gages) used in the course of testing to measure, record, or verify an environment or condition shall have been calibrated and shall have valid current calibration decals.

5.2 Test Measurement Tolerances

Ambient Temperature	$70 \pm 15^{\circ}\text{F}$
Test Temperatures	$\pm 5^{\circ}\text{F}$
Relative Humidity	$\pm 5\%$
Exposure Time	15 Min. or less ± 1 Min. Greater than 15 Min. ± 2 Min. Greater than 8 Hr ± 1 Hrs.
Vertical Rain Rates	3.5 ± 2 In/Hr 8.7 ± 3 In/Hr 21 ± 4 In./Hr

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Wind Rates

6.4+2 Knots

50+5 - 15 Knots

6.0 TEST PROCEDURES

6.1 Test Setup Verification

6.1.2 Rain/Wind Test setups

6.1.2.1 Verify the rain and the wind rates for each of the test conditions (A,B and C) defined in Table 1 prior to each exposure in accordance with the applicable with the applicable paragraphs and checklists of GOP 3841-001

6.1.2.2 Record the details of each verification test on test data sheets and summarize in the Laboratory Notebook.

6.2 Wind/Rain Exposure

6.2.1 Specimen Preparation

6.2.1.1 Disassemble, weigh and reassemble each specimen before and after each wind/rain exposure.

6.2.1.1.1 Record weights, date, time, temperature and relative humidity on approved data sheets.

6.2.3 Install the specimen in the test facility specified and expose it to the wind/rain environment in accordance with paragraph 6.2.3.1 of this DTP.

6.2.3.1 Test Condition Tolerances

Table 1

Test Condition	Installation Rain Chamber	Installation Orientation	Exposure Duration (Min)	Environment Wind (Knots)	Environment Vertical Rain (In/Hr)
A	A	45°	63 to 67	None	2.5 to 5.5
B	B	45°	24 to 28	4.4 to 8.4	5.7 to 11.7
C	B	90°	9 to 11	35 to 55	17 to 25

6.2.3.2 Record specimen number, average wind and rain rate calibration data, test data, test start time, ambient air temperature, system water flow rate, the nozzle pressures in the Laboratory Notebook for each environment exposure.

7.0 SPECIMEN DISPOSITION

Transfer the test specimens to the RTE or his representative for disposition.

APPENDIX G

SALT SPRAY TESTING

EFFECT OF SALT SPRAY ON CFBI DETAILED TEST PROCEDURE

INTRODUCTION:

This Detailed Test Procedure (DTP) defines plasma arc exposure testing for CFBI test specimens. These specimens consists of two each for three different surface salt conditions.; no salt, 2.3 to 2.5 gms/sq meter and .08 to .12 gm/sq. meter. One specimen of each salt condition is to be exposed to five 1500⁰F test cycles and one specimen of each condition is to be exposed to five 1800⁰F test cycles. The thermal tests will be performed at NASA/AMES 20MW Plasma Test Facility.

TEST OBJECTIVE

To evaluate the influence of residual salt on the CFBI thermal performance

SCOPE

This document describes test conditions required by Test Plan for Task 2 and is limited to those tests. The actual facility operations and related procedures will be the responsibility of NASA/AMES. Changes to this plan which are in the scope of the test request may be made by "Redline" changes approved by the Responsible Test Engineer.

APPLICABLE DOCUMENTS

The following documents are applicable to this test.

1. Test Plan for Task 2 "Evaluation of Advanced Flexible TPS With MLI"
2. Quality Assurance Specification and Quality Requirements for off site test, MT0802-105A
3. The Laboratory & Test (L&T) administrative document is The Laboratory Request LR 6447
4. Rockwell Laboratory notebook for recording observations during testing.
5. Disposition Record Form for recording test deviations and anomalies during testing.

TEST SPECIMEN PREPARATION

1. CFBI Fabrication shall be by d/284 to the requirements and procedures defined on the test request.

2. Notice of Test - The RTE shall be notified in advance of any scheduled test.
3. Photographic Coverage - Color photographs will be taken of the test panels when any visual variance from initial condition is noticed.
4. Inspection - A general visual inspection of the test panel and fixture shall be made prior to the start of the test . A complete visual inspection along with color photographs shall be made after each test in order to determine any damage that might occur. Flexibility of the blanket shall be determined after each plasma flow exposure of the last specimen to determine if blankets stiffened. One method of blanket stiffness determination will be to flex the Outer Mold Line (OML) with a finger.
5. Report - NASA/Ames shall publish a test agency report at the completion of the test program while the RTE shall publish an interpretative Laboratory Test Report (LTR).

TEST PROCEDURE

NASA/Ames shall provide the facility apparatus, setup, data acquisition, data reduction and facility detailed test procedure for plasma exposure.

Test Conditions - The OML surface of the blanket specimens shall be exposed to a heating environment per Table 1 resulting in the LRSI control surface temperature shown in figure 5 at minimum attainable chamber pressure. Maximum soak and temperature on the aluminum substrate backface shall be limited to 350⁰F by use of a coldplate (figure 5) or other technique chosen by the test agency and approved by the RTE. An optical pyrometer shall be used to monitor the surface temperature of the blankets (approximately 2 microns narrow band sensor for best results). The pyrometer data acquisition shall be non-interference with the plasma test exposures.

Routine test procedures shall be the responsibility of the testing agency (NASA/Ames).

Pre-test Calibration - The test environment of NASA/Ames 20 MW plasma arc facility shall be demonstrated by a series of runs using an LRSI tile calibration model instrumented with 20 type "R" 30 gauge thermocouples. See Figure 6 for a sketch of the LRSI hot wall calibration model. This model is made from a 14.5" x17.5x 1/8" thick aluminum plate onto which are bonded four instrumented LRSI tiles leaving a nominal one inch of aluminum exposed on all edges.

Test specimens shall be visually inspected before insertion into the test chamber.

After calibrations are made each bonded blanket test specimen shall be placed in the test fixture holder and exposed thermally to plasma flow following the profile of figure 5.

Prior to starting a test run the temperature of the test article shall be below 100⁰F and the test instrumentation shall be checked for continuity.

Prior to each test run and after each test run the test specimen shall be examined for flexibility. NASA/Ames is responsible for all data acquisition.

All measurements during thermal exposure (including temperature and pressure) are to be continuously recorded. Test data shall be recorded on magnetic tape and strip charts per facility capability. Data tabulations, CRT's and computer plots shall be furnished by NASA/Ames at the completion of each test run.

The tabulated raw data, temperature, pressures, times and heater parameters shall be furnished to the RTE, as soon as possible after each test run.

The tabulated raw data, temperatures, pressures, times and heater parameters shall be furnished to the RTE, as soon as possible after each test run. NASA/Amass shall furnish computer graphs of the thermocouples for all test specimen thermocouple versus time and pressure versus time shall be provided to the RTE within two weeks after test.

TEST ARTICLE DISPOSITION

At the completion of the test the test specimens shall be returned to Rockwell, Space Systems Division, Laboratories and Test, Dept. 284 for retention.

**THERMAL EXPOSURE
TABLE 1**

SPECIMEN #	SALT EXPOSURE	THERMAL EXPOSURE*
1	none	none
2	none	none
3	none	1500F
4	none	1800F
5	2.3 to 2.5 gms/sq meter	1500F
6	2.3 to 2.5 gms/sq meter	1800F
7	.08 to .12 gms/sq meter	1500F
8	.08 to .12 gms/sq/ meter	1800F

*Specimens are exposed to 5 cycles of temperature environment of Figure 5.

APPENDIX H

VIBROACOUSTICS TESTING

**THERMAL PROTECTION SYSTEM
PROGRESSIVE WAVE TUBE VIBROACOUSTIC TESTING
DETAILED TEST PROCEDURE
NRA 8-12, SSTO TA-3**

DYNAMICS TEST ENGINEER: JIM McGEE

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- 1.0. INTRODUCTION AND TEST SPECIMEN DESCRIPTION
- 2.0. SCOPE
- 3.0. APPLICABLE DOCUMENTS
- 4.0. GENERAL REQUIREMENTS
- 5.0. DETAILED REQUIREMENTS
- 6.0. PROCEDURES
 - 6.1. TEST SETUP PROCEDURES
 - 6.1.1. MECHANICAL SETUP
 - 6.1.2. EXCITATION, INSTRUMENTATION, AND DATA SETUP
 - 6.2. TEST READINESS REVIEW
 - 6.3. TEST PROCEDURE NOTES
 - 6.3.1. EVENT IDENTIFICATION
 - 6.3.2. TEST PERSONNEL
 - 6.3.3. SYSTEM EQUALIZATION/PRELIMINARY TEST RUNS
 - 6.3.4. EMERGENCY SHUTDOWN PROCEDURE
 - 6.4. TEST RUN PROCEDURES
 - 6.5. TEST SETUP TEARDOWN
 - 6.6. TEST SPECIMEN DISPOSITION
- 7.0. DATA REQUIREMENTS
- 8.0. TEST EQUIPMENT
- 9.0. FIGURES AND TABLES
- APPENDICES
 - A.1. EMERGENCY SHUTDOWN PROCEDURE

1.0. INTRODUCTION AND TEST SPECIMEN DESCRIPTION.

1.1. INTRODUCTION.

This procedure details the steps for vibroacoustic testing of lightweight durable thermal protection system materials for the SSTO.

1.2. SPECIMEN.

The test specimens will be those specimens tested under NRA8-12, Lightweight Durable Thermal Protection System (TA-3).

1.3. TEST DESCRIPTION

1. Task 2, ID 5h: Flexible TPS blanket/MLI composite in a progressive wave tube acoustic environment at 160 dB SPL.
2. Task 4, ID 6f: Direct bond AETB tiles to graphite composite substrate in a progressive wave tube acoustic environment at 160 dB SPL.
3. Task 4, ID 6p: Ceramic matrix composite tile cover attached to AETB substrate in a progressive wave tube acoustic environment at 160 dB SPL.
4. Other tasks as required.

2.0. SCOPE.

2.1. PURPOSE

The purpose of this testing will be to evaluate advanced TPS components for the SSTO, subjected to vibroacoustic environments.

2.2. OBJECTIVES

1. Demonstrate Flexible TPS/MLI composite blanket performance in a vibroacoustic environment.

2. Determine performance of direct-bond tiles subjected to vibroacoustic loads.
3. Evaluate CMC covers subjected to vibroacoustic loads.
4. Other vibroacoustic testing as required.

3.0. APPLICABLE DOCUMENTS.

The following Rockwell SSD specifications, drawings, and documents, are applicable to the performance of the tests:

1. Advanced Structures and TPS Technologies (NRA8-12) Test Plans for TA-3, especially Task 2 and Task 4 Plans;
2. Rockwell/SSD Safety Operating Manual - Pub. 2548-R, Rev. 1991;
3. Laboratories, Test, and Material Sciences Drawings TBD;

4.0. GENERAL REQUIREMENTS.

4.1. SPECIMEN LOG

A Laboratory Notebook shall be kept to record all moves, adjustments, setup information for excitation systems, instrumentation systems, specimen attachments, and other subsystems, setup changes, and test runs. Pertinent information regarding data shall also be recorded.

4.2. TEST DATA

All notes necessary for proper understanding of the test data shall be recorded in the Laboratory Notebook. Test data shall be in the form of third-octave plots of sound pressure level versus frequency for microphone data channels, and narrow-band plots of acceleration power spectral density versus frequency for accelerometers. Plots of acceleration versus frequency for accelerometers

will also be available for swept sine vibration tests. Strain gage data shall be in a form comparable to accelerometer data, using appropriate engineering units. Time domain plots will also be available upon request for all data.

4.3. NOTICE OF TEST

The Engineering Test Requester, or an assigned representative, shall be notified prior to the start of each test run, with sufficient advance notice to be in attendance.

4.4. FAILURE AND INCIDENT REPORTING

In the event that a specimen failure or incident occurs, after immediately securing the area, the test personnel shall notify the test requester and all pertinent program and functional management personnel.

4.5. TEST REPORTING

Upon completion of all tests, a White Test Report and copies of all Laboratory Notebook pages shall be prepared and issued to the test requester.

4.6. DISPOSITION OF TEST HARDWARE

Upon completion of all tests, the test specimens shall be returned to the Test Requester for disposition.

5.0. DETAILED REQUIREMENTS.

5.1. EQUIPMENT CALIBRATION

All measurement equipment used on the test shall be calibrated with traceability to the National Institute of Standards and Technology (NIST). Date tags or decals shall be attached to applicable equipment or their storage boxes, which indicate that such calibration is current. Deviations will be approved by the Engineering Test Requesters. Verification of instrument calibrations and due dates shall be performed prior to test. Equipment calibration information shall be recorded in the laboratory notebook.

5.2. TOLERANCES

Required tolerances of test conditions and data will be determined and approved by the Engineering Test Requesters.

5.3. QUALIFICATION CRITERIA

NRA8-12 TA-3 tests are engineering development tests, and therefore qualification criteria is not applicable.

5.4. TEST SEQUENCE

In lieu of requests by the Engineering Test Requester, the sequence of tests will be determined by the Responsible Test Engineer.

6.0. PROCEDURES

CAUTION: ALL NECESSARY MEASURES SHALL BE TAKEN TO PROTECT THE TEST SPECIMEN FROM ANY DAMAGE WHILE MOVING IT, MOVING OTHER HARDWARE AROUND THE TEST SPECIMEN, MOUNTING THE TEST SPECIMEN, OR ATTACHING INSTRUMENTATION TO THE TEST SPECIMEN. ACCESS TO THE TEST SPECIMEN SHALL GENERALLY BE LIMITED TO TEST PERSONNEL ONLY.

6.1. TEST SETUP PROCEDURES

NOTE: Refer to figure 1 for a flow diagram of the Acoustic Test Facility, including plumbing, excitation, and instrumentation systems.

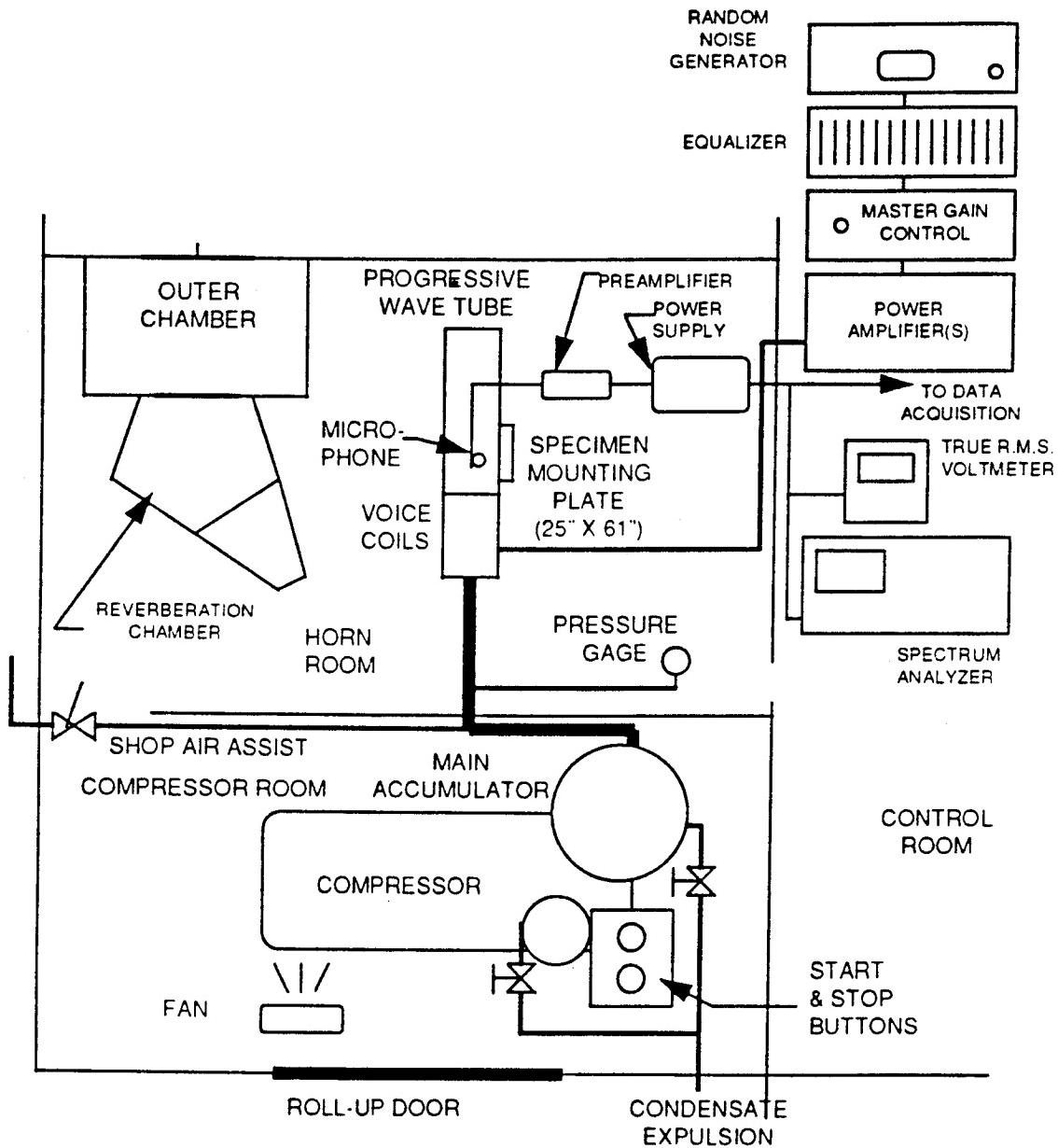


FIGURE 1: Acoustic Test Facility and Setup

WARNING: WHEN WORKING ABOVE OR AROUND THE TEST SPECIMEN, OR IN AN AREA WHERE OTHER PERSONNEL MAY BE BELOW, ANY LOOSE EQUIPMENT THAT MAY BE DROPPED SHALL BE TETHERED, TO PREVENT DAMAGE TO THE SPECIMEN OR INJURY.

6.1.1. INSTRUMENTATION SETUP AND CHECKOUT

- 6.1.1.1. Select appropriate microphones for the sound to be measured. Hook up the microphones to the preamplifiers.
- 6.1.1.2. Connect the preamplifiers to the microphone power supplies. Connect the output of the microphone power supplies to the appropriate data patches. Turn on the microphone power supplies an adequate period of time for warming up prior to taking any measurements, including calibrations.
- 6.1.1.3. Connect the data patches or microphone power supplies to a spectrum analyzer or a true R.M.S. voltmeter for measurement of the channel outputs.
- 6.1.1.4. Insert each microphone to be calibrated into a calibrator piston phone. Turn on the piston phone. Read the overall sound pressure level and, if using a spectrum analyzer, the level at the band of the calibrator piston phone. If using a calibrator piston phone with different output levels, set the calibrator piston phone at different levels to determine linearity. If linearity is not accurate, note the results of the linearity check in the lab notebook, and use the calibrator piston phone setting closest to the overall sound pressure level at which the test will be run. Determine the reference voltage corresponding to a reference sound pressure level. This will be known as the "calibration voltage."
- 6.1.1.5. After calibration voltages are determined, install the microphones at their appropriate location in the progressive wave tube or reverberation chamber.

6.1.2. CHAMBER AND AREA SETUP AND CHECKOUT

- 6.1.2.1. Verify that the voice coil box is attached to the appropriate acoustic test chamber (progressive wave tube or reverberation chamber).

- 6.1.2.2 Verify that the voice coil box and chamber are not obstructed with significant amounts of dirt, rags, or other debris.
- 6.1.2.3. If the progressive wave tube is being used, attach the test specimen panel to the side of the tube (61" wide by 25" high opening). If the reverberation chamber is being used, attach the door panel (47.5" wide by 59.5" high opening), if necessary for this test. If the excitation test level has not yet been set up, the test specimen panel should be installed on the chamber without the specimen, if possible, to setup the level. Close the outer chamber doors regardless of which chamber is used prior to starting the compressor.

6.1.3. LEVEL CONTROL SETUP

- 6.1.3.1. Install a blank test specimen panel, if possible, on the chamber, prior to installing the test specimen in the chamber. The following steps include the Compressor Startup and Voice Coil Excitation procedure steps:
- 6.1.3.2. Open the roll-up door.
- 6.1.3.3. Turn on the fan so that adequate air flow is present to cool the compressor.
- 6.1.3.4. Close the two red condensate expulsion valves.
- 6.1.3.5. Push the "START" button, and hold it in for at least a full second for the compressor to stay running. The compressor pressure gage should read approximately 40-45 p.s.i.g.
- 6.1.3.6. Open the shop air assist valve.
- 6.1.3.7. The pressure gage in the horn room on the pipe leading directly to the voice coils should read approximately 40 p.s.i.g.
- 6.1.3.8. Verify air flow through the voice coils. THIS IS VERY IMPORTANT! If there is no air flow through the voice coils, the coils will burn up when current is applied. The pressure switch should normally prevent electrical current flow when no air flow is present, but this must be verified.
- 6.1.3.9. Verify that the doors to the horn room are closed. Verify that the power amplifier master gain control is off.
- 6.1.3.10. Turn on the random noise generator.
- 6.1.3.11. Turn on the power amplifiers.
- 6.1.3.12. Slowly bring up the master gain until the desired overall level is achieved.
- 6.1.3.13. Using a spectrum analyzer to read the levels at each individual band (octave, third-octave, or other) adjust the equalizer until the relative level at each band is correct

relative to the other bands. Spectrum shape is TBD.
Nominal overall test level is 160 dB SPL.

- 6.1.3.14. Using the spectrum analyzer or a true R.M.S. voltmeter to read the overall level, determine if the overall level is correct. If not, slowly adjust the master gain until the overall level is correct.
- 6.1.3.15. Upon completion of the level control setup, turn down the master gain, power down the electrical excitation equipment, and shut down the compressor, using the above steps in reverse order.

6.1.4. SPECIMEN SETUP AND FINAL TEST PREPARATION

- 6.1.4.1. The acoustic test shall be set up and performed per Rockwell Space Systems Division LT&MS Dynamics Laboratory standard practices.
- 6.1.4.2. Mount response accelerometers on the test specimen or fixturing, and control and response microphones in the appropriate test chamber, as requested by Engineering.
- 6.1.4.3. Mount the test specimen and fixture in the appropriate acoustic test chamber, per instruction from the Responsible Dynamics Test Engineer.
- 6.1.4.4. Complete instrumentation setup between all transducers and the data acquisition system. The data acquisition system may include a spectrum analyzer, FM tape recorders, the workstation based Dynamic Data Acquisition and Analysis System, or a combination of the above. Verify that this setup is complete and accurate by performing an end-to-end check and a calibration for all transducer channels. The calibration signals, consisting of generated sine waves at the calibration voltages, shall be recorded on the data acquisition system prior to testing, but not necessarily prior to every test run if multiple test runs are performed during any one work shift.

6.2. TEST READINESS REVIEW

A Test Readiness Review shall be held between the test requester and the dynamics test engineer prior to test.

6.3. TEST PROCEDURE NOTES

6.3.1. EVENT IDENTIFICATION

The following definitions shall apply:

1. Test- A complete set or subset of vibroacoustic test runs on a specimen.
2. Run- One application of vibroacoustics excitation to the specimen.

6.3.2. TEST PERSONNEL

The minimum test personnel necessary to perform test runs is one dynamics test engineer, working in coordination with an engineering test requester. The dynamics test engineer may use a dynamics test technician as an addition or replacement, when appropriate.

6.3.3. SYSTEM EQUALIZATION/PRELIMINARY TEST RUNS

Preliminary test runs may be necessary to perform system checkouts (end-to-end checks), establish test levels, shaker configurations, and other parameters, prior to performing actual testing or data runs.

6.3.4. EMERGENCY SHUTDOWN PROCEDURE

An Emergency Shutdown Procedure is in Sub-Appendix A, the last page of this Vibroacoustics Detailed Test Procedure.

6.4. TEST RUN PROCEDURES

6.4.1. Verify that all steps in section 6.1 have been completed before proceeding.

6.4.2. COMPRESSOR STARTUP

6.4.2.1. Open the roll-up door.

6.4.2.2. Turn on the fan so that adequate air flow is present to cool the compressor.

6.4.2.3. Close the two red condensate expulsion valves.

- 6.4.2.4. Push the "START" button, and hold it in for at least a full second for the compressor to stay running. The compressor pressure gage should read approximately 40-45 p.s.i.g.
- 6.4.2.5. Open the shop air assist valve.
- 6.4.2.6. The pressure gage in the horn room on the pipe leading directly to the voice coils should read approximately 40 p.s.i.g.

6.4.3. VOICE COIL EXCITATION

- 6.4.3.1. Verify air flow through the voice coils. THIS IS VERY IMPORTANT! If there is no air flow through the voice coils, the coils will burn up when current is applied. The pressure switch should normally prevent electrical current flow when no air flow is present, but this must be verified.
- 6.4.3.2. Verify that the doors to the horn room are closed. Verify that the power amplifier master gain control is off.
- 6.4.3.3. Turn on the random noise generator.
- 6.4.3.4. Turn on the power amplifiers.

6.4.5. TEST PERFORMANCE & DATA ACQUISITION

- 6.4.5.1. Prior to the start of the test, verify that the steps in sections 6.4.1, 6.4.2, and 6.4.3, have been completed. Verify that any other required parameters of the test setup are complete and confirm that all participating test personnel are on line on the intercom and ready to perform their test duties.
- 6.4.5.2. Start the data acquisition prior to beginning excitation.
- 6.4.5.3. While monitoring the overall sound pressure level on a true R.M.S. voltmeter and the spectrum shape on a spectrum analyzer, slowly increase the master gain until the correct test excitation level is achieved. Time the test run. Monitor, and adjust as necessary, overall level and spectrum shape throughout the test. When the required test time has been completed, slowly turn down the master gain and then stop the data acquisition.
- 6.4.5.4. Upon completion of testing, turn off the power amplifiers. Shut down the compressor by performing the steps in section 6.4.2 in exactly reverse order:
 - 6.4.5.4.1. Close the shop air assist valve.
 - 6.4.5.4.2. Push the "STOP" button to shut down the compressor.

- 6.4.5.4.3. Open the two red condensate expulsion valves.
- 6.4.5.4.4. Turn off the fan.
- 6.4.5.4.5. Close the roll-up door.

6.5. TEST SETUP TEARDOWN

After completion of testing, all instrumentation and other test equipment shall be removed from the specimen, unless otherwise agreed to by the engineering test requester and the test engineer. The test specimen shall be removed from the acoustic chamber.

6.6. TEST SPECIMEN DISPOSITION

After completion of testing and setup teardown, transfer the test specimen to the test requester or designated representative for disposition.

7.0. DATA REQUIREMENTS

7.1. HARD COPIES

Hard copies of data plots, per paragraph 4.2, shall be made available to the test requester. Sample data sheets are shown in Figure 2 for microphone data and Figure 3 for accelerometer data.

FLEXIBLE TPS TEST PANEL--RUN # 1

OVERALL LEVEL = 160.0 dB SPL

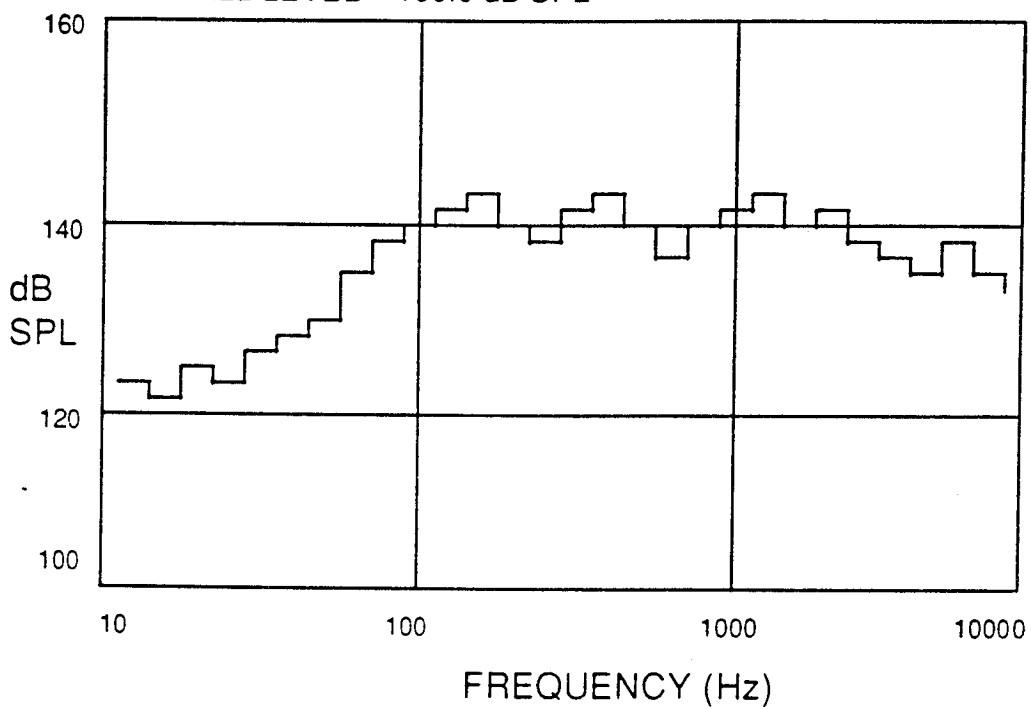


FIGURE 2: Sample Data Sheet for Microphone Data

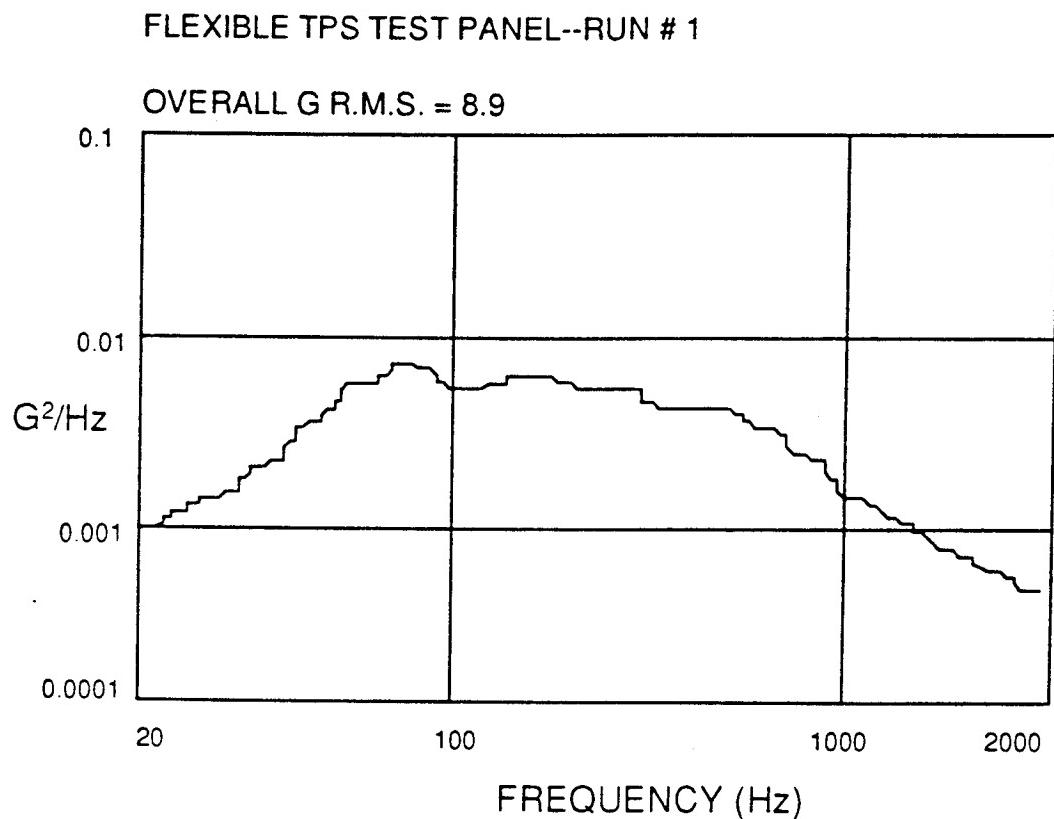


FIGURE 3: Sample Data Sheet for Accelerometer Data

7.2. DATA FILES

All data for all test runs shall be stored on magnetic media for the duration of the program, or until the test requester concurs that the data can be disposed of.

7.3. TEST REPORT

A White Test Report and copies of all Laboratory Notebook pages shall be prepared and issued to the test requester.

8.0. TEST EQUIPMENT.

The following test equipment will be utilized for the test:

8.1. MECHANICAL SYSTEM.

Progressive wave tube acoustic chamber
Test specimen panel
Attachment hardware
Voice coils
Compressor and associated plumbing
Indication pressure gauges
Fan
Shop air assist valve

8.2. ELECTRICAL EXCITATION SYSTEM

Random noise generator
Equalizer
Master gain control
Power amplifiers

8.3. INSTRUMENTATION

Microphone
Microphone preamplifier
Microphone power supply
True R.M.S. voltmeter
Spectrum analyzer
Accelerometers

Charge amplifiers
Other sensors (optional)
Other signal conditioning (optional)
F.M. tape recorder (optional)
Digital data acquisition system (optional)

SUB-APPENDIX A: EMERGENCY PROCEDURES

A.1. EMERGENCY PROCEDURES

1. Any member of the test team noting an abnormal condition shall immediately notify the Dynamics Test Engineer or his designated representative, hereinafter referred to as the Test Conductor.
2. The Test Conductor has the sole responsibility to order the excitation removed during test.

A.2. EMERGENCY SHUTDOWN PROCEDURE

1. Upon becoming aware of an abnormal test condition, the Test Conductor shall immediately make a judgment as to whether the excitation level should be reduced or shut down.

*** N O T E ***

IF THE TEST CONDUCTOR AND THE ENGINEERING TEST REQUESTER CONCUR THAT THE ABNORMAL TEST CONDITIONS EXPERIENCED ARE NOT DETRIMENTAL TO THE TEST SPECIMEN AND THAT DATA ACQUISITION AT THAT LEVEL OF EXCITATION WOULD BE ADVANTAGEOUS TO THE TEST OBJECTIVES, THE ABNORMAL TEST CONDITIONS MAY BE IGNORED BY THE TEST CONDUCTOR AND DATA ACQUISITION MAY PROCEED.

2. At any time an emergency exists that requires immediate shutdown, the Test Conductor shall issue an order for the nearest test personnel to reduce the master gain.

APPENDIX I

VIBRATION TESTING

DTP 6451-818
PAGE 1

**MECHANICAL VIBRATION TESTING
DETAILED TEST PROCEDURE
NRA 8-12, SSTO TA-3**

DYNAMICS TEST ENGINEER: JIM McGEE

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1.0. INTRODUCTION AND TEST SPECIMEN DESCRIPTION.

1.1. INTRODUCTION.

This procedure details the steps for mechanical vibration testing of lightweight durable thermal protection system materials for the SSTO.

1.2. SPECIMEN.

The test specimens will be those specimens tested under NRA8-12, Lightweight Durable Thermal Protection System (TA-3).

1.3. TEST DESCRIPTION

1. Task 2, ID 5h: Flexible TPS blanket/MLI composite in a mechanical vibration/deflection environment at 0.067 g²/Hz, or TBD.
2. Other tasks as required.

2.0. SCOPE.

2.1. PURPOSE

The purpose of this testing will be to evaluate advanced TPS components for the SSTO, subjected to mechanical vibration/deflection environments.

2.2. OBJECTIVES

1. Demonstrate Flexible TPS/MLI composite blanket performance in a mechanical vibration/deflection environment.
2. Other mechanical vibration/deflection testing as required.

3.0. APPLICABLE DOCUMENTS.

The following Rockwell SSD specifications, drawings, and documents, are applicable to the performance of the tests:

1. Advanced Structures and TPS Technologies (NRA8-12) Test Plans for TA-3, especially Task 2 Plan;
2. Rockwell/SSD Safety Operating Manual - Pub. 2548-R, Rev. 1991;
3. Laboratories, Test, and Material Sciences Drawings *TBD*;

4.0. GENERAL REQUIREMENTS.

4.1. SPECIMEN LOG

A Laboratory Notebook shall be kept to record all moves, adjustments, setup information for excitation systems, instrumentation systems, specimen attachments, and other subsystems, setup changes, and test runs. Pertinent information regarding data shall also be recorded.

4.2. TEST DATA

All notes necessary for proper understanding of the test data shall be recorded in the Laboratory Notebook. Test data shall be in the form of narrow-band plots of acceleration power spectral density versus frequency for accelerometers. Plots of acceleration versus frequency for accelerometers will also be available for swept sine vibration tests. Strain gage data shall be in a form comparable to accelerometer data, using appropriate engineering units. Time domain plots will also be available upon request for all data.

4.3. NOTICE OF TEST

The Engineering Test Requester, or an assigned representative, shall be notified prior to the start of each test run, with sufficient advance notice to be in attendance.

4.4. FAILURE AND INCIDENT REPORTING

In the event that a specimen failure or incident occurs, after immediately securing the area, the test personnel shall notify the test requester and all pertinent program and functional management personnel.

4.5. TEST REPORTING

Upon completion of all tests, a White Test Report and copies of all Laboratory Notebook pages shall be prepared and issued to the test requester.

4.6. DISPOSITION OF TEST HARDWARE

Upon completion of all tests, the test specimens shall be returned to the Test Requester for disposition.

5.0. DETAILED REQUIREMENTS.

5.1. EQUIPMENT CALIBRATION

All measurement equipment used on the test shall be calibrated with traceability to the National Institute of Standards and Technology (NIST). Date tags or decals shall be attached to applicable equipment or their storage boxes, which indicate that such calibration is current. Deviations will be approved by the Engineering Test Requesters. Verification of instrument calibrations and due dates shall be performed prior to test. Equipment calibration information shall be recorded in the laboratory notebook.

5.2. TOLERANCES

Required tolerances of test conditions and data will be determined and approved by the Engineering Test Requesters.

5.3. QUALIFICATION CRITERIA

NRA8-12 TA-3 tests are engineering development tests, and therefore qualification criteria is not applicable.

5.4. TEST SEQUENCE

C-3.

In lieu of requests by the Engineering Test Requester, the sequence of tests will be determined by the Responsible Test Engineer.

6.0. PROCEDURES.

CAUTION: ALL NECESSARY MEASURES SHALL BE TAKEN TO PROTECT THE TEST SPECIMEN FROM ANY DAMAGE WHILE MOVING IT, MOVING OTHER HARDWARE AROUND THE TEST SPECIMEN, MOUNTING THE TEST SPECIMEN, OR ATTACHING INSTRUMENTATION TO THE TEST SPECIMEN. ACCESS TO THE TEST SPECIMEN SHALL GENERALLY BE LIMITED TO TEST PERSONNEL ONLY.

6.1. TEST SETUP PROCEDURES

NOTE: Refer to Figure 1 for a flow diagram of a typical mechanical vibration test setup.

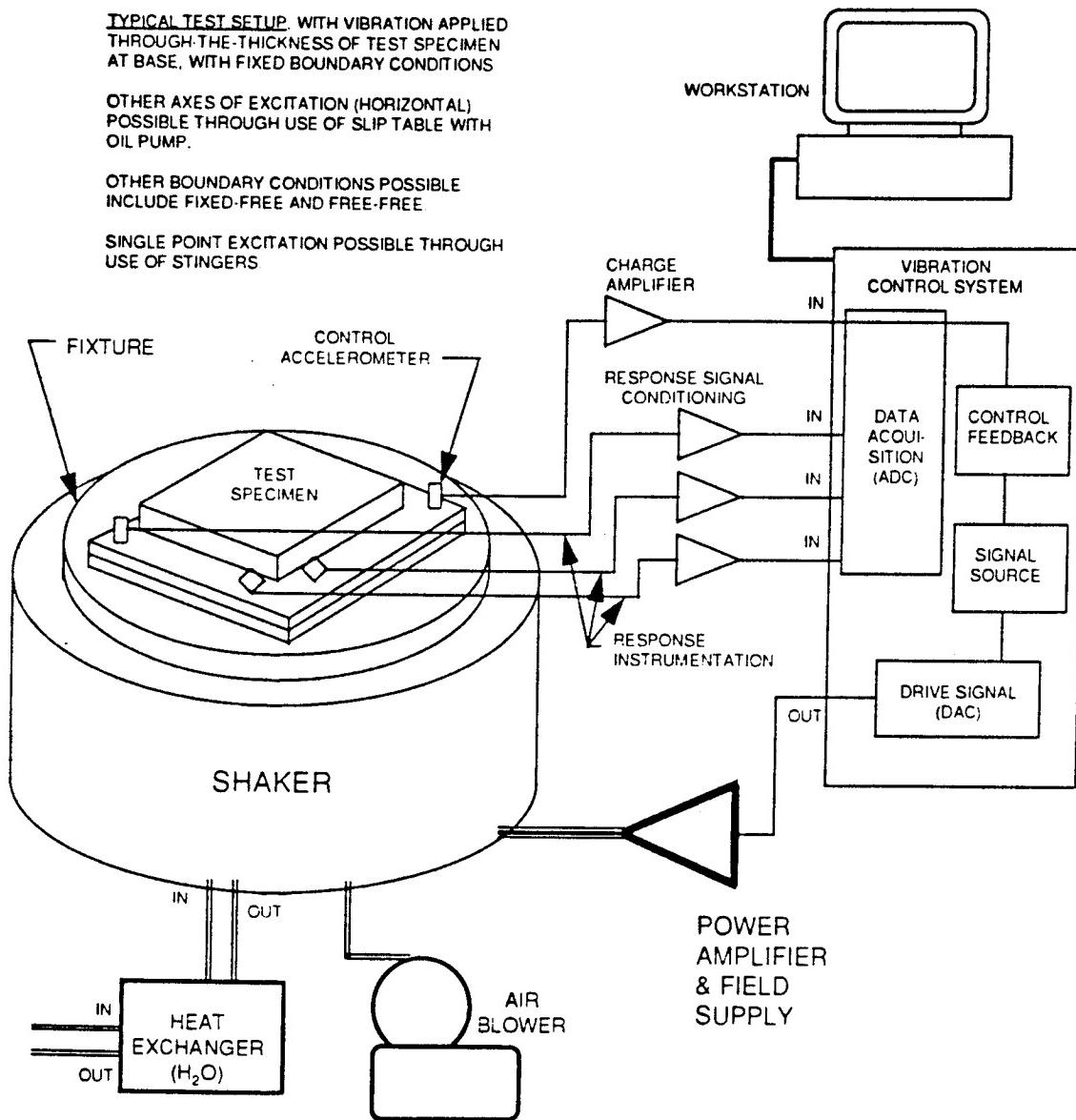


FIGURE 1: Typical Mechanical Vibration Test Setup

WARNING: WHEN WORKING ABOVE OR AROUND THE TEST SPECIMEN, OR IN AN AREA WHERE OTHER PERSONNEL MAY BE BELOW, ANY LOOSE EQUIPMENT THAT MAY BE DROPPED SHALL BE TETHERED, TO PREVENT DAMAGE TO THE SPECIMEN OR INJURY.

6.1.1. The vibration test shall be set up and performed according to standard Rockwell Space Division Vibration Laboratory practices. Program the vibration control system to perform the following spectra for each axis:

6.1.1.1. X-axis:

20 Hertz to 80 Hertz @ +3 dB/octave,
80 Hertz to 350 Hertz @ 0.067 g²/Hertz,
350 Hertz to 2000 Hertz @ -3 dB/octave;

or *TBD*.

6.1.1.2. Y-axis:

20 Hertz to 80 Hertz @ +3 dB/octave,
80 Hertz to 350 Hertz @ 0.067 g²/Hertz,
350 Hertz to 2000 Hertz @ -3 dB/octave;

or *TBD*.

6.1.1.3. Z-axis:

20 Hertz to 80 Hertz @ +3 dB/octave,
80 Hertz to 350 Hertz @ 0.067 g²/Hertz,
350 Hertz to 2000 Hertz @ -3 dB/octave;

or *TBD*.

6.1.2. Mount response accelerometers on the test specimen, as requested by the Engineering Test Requester.

- 6.1.3. Mount the test fixture onto the vibration exciter and install the control accelerometer on the fixture for the first axis to be tested, per instruction from the Responsible Vibration Test Engineer.
- 6.1.4. Install the test specimen on the test fixture for vibration in the first axis to be tested.
- 6.1.5. Complete instrumentation setup between all transducers and the data acquisition system. Verify that this setup is complete and accurate by performing an end-to-end check and a calibration recording for all transducer channels. The calibration signal shall be recorded on the data acquisition system prior to testing, but not necessarily prior to every test run if multiple test runs are performed during any one shift.

6.2. TEST READINESS REVIEW

A Test Readiness Review shall be held between the test requester and the dynamics test engineer prior to test.

6.3. TEST PROCEDURE NOTES

6.3.1. EVENT IDENTIFICATION

The following definitions shall apply:

1. Test- A complete set or subset of vibration test runs on a specimen.
2. Run- One application of vibration excitation to the specimen.

6.3.2. TEST PERSONNEL

The minimum test personnel necessary to perform test runs is one dynamics test engineer, working in coordination with an engineering test requester. The dynamics test engineer may use a dynamics test technician as an addition or replacement, when appropriate.

6.3.3. SYSTEM EQUALIZATION/PRELIMINARY TEST RUNS

Preliminary test runs may be necessary to perform system checkouts (end-to-end checks), establish test levels, shaker configurations, and other parameters, prior to performing actual testing or data runs.

6.3.4. EMERGENCY SHUTDOWN PROCEDURE

An Emergency Shutdown Procedure is in Sub-Appendix A, the last page of this Mechanical Vibration Detailed Test Procedure.

6.4. TEST RUN PROCEDURES

- 6.4.1. Verify that all steps in section 6.1 have been completed before proceeding.
- 6.4.2. Verify that the test setup is complete for the first axis to be tested and confirm that all test personnel are on line and ready to perform their test duties.
- 6.4.3. Perform vibration for the first axis to be tested. The data acquisition shall be turned on during vibration equalization prior to reaching full level, to record all vibration data while testing at full level. A minimum of one power spectral density measurement of the full level control accelerometer signal shall be taken.
- 6.4.4. Mount the test fixture onto the vibration exciter and install the control accelerometer on the fixture for the second axis to be tested, per instruction from the Responsible Vibration Test Engineer.
- 6.4.5. Install the test specimen on the test fixture for vibration in the second axis to be tested.
- 6.4.6. Complete instrumentation setup between all transducers and the data acquisition system. Verify that this setup is complete and accurate by performing an end-to-end check and a calibration recording for all transducer channels. The

calibration signal shall be recorded on the data acquisition system prior to testing, but not necessarily prior to every test run if multiple test runs are performed during any one shift.

- 6.4.7. Verify that the test setup is complete for the second axis to be tested and confirm that all test personnel are on line and ready to perform their test duties.
- 6.4.8. Perform vibration for the second axis to be tested. The data acquisition shall be turned on during vibration equalization prior to reaching full level, to record all vibration data while testing at full level. A minimum of one power spectral density measurement of the full level control accelerometer signal shall be taken.
- 6.4.9. Mount the test fixture onto the vibration exciter and install the control accelerometer on the fixture for the third axis to be tested, per instruction from the Responsible Vibration Test Engineer.
- 6.4.10. Install the test specimen on the test fixture for vibration in the third axis to be tested.
- 6.4.11. Complete instrumentation setup between all transducers and the data acquisition system. Verify that this setup is complete and accurate by performing an end-to-end check and a calibration recording for all transducer channels. The calibration signal shall be recorded on the data acquisition system prior to testing, but not necessarily prior to every test run if multiple test runs are performed during any one shift.
- 6.4.12. Verify that the test setup is complete for the third axis to be tested and confirm that all test personnel are on line and ready to perform their test duties.
- 6.4.13. Perform vibration for the third axis to be tested. The data acquisition shall be turned on during vibration equalization prior to reaching full level, to record all vibration data while testing at full level. A minimum of one power spectral density measurement of the full level control accelerometer signal shall be taken.

6.5. TEST SETUP TEARDOWN

After completion of testing, all instrumentation and other test equipment shall be removed from the specimen, unless otherwise agreed to by the engineering test requester and the test engineer. The test specimen shall be removed from the vibration exciter.

6.6. TEST SPECIMEN DISPOSITION

After completion of testing and setup teardown, transfer the test specimen to the test requester or designated representative for disposition.

7.0. DATA REQUIREMENTS.

7.1. HARD COPIES

Hard copies of data plots, per paragraph 4.2, shall be made available to the test requester. Sample data sheets are shown in Figure 2 for accelerometer data and Figure 3 for strain gauge data.

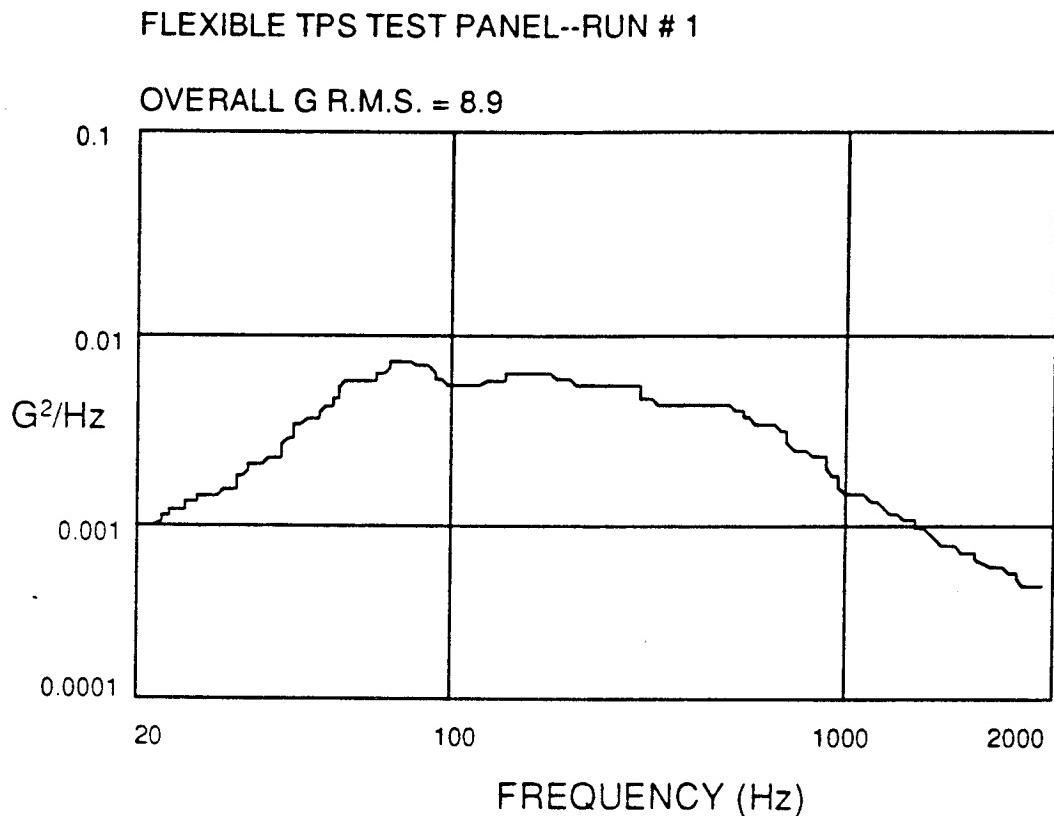


FIGURE 2: Sample Data Sheet for Accelerometer Data

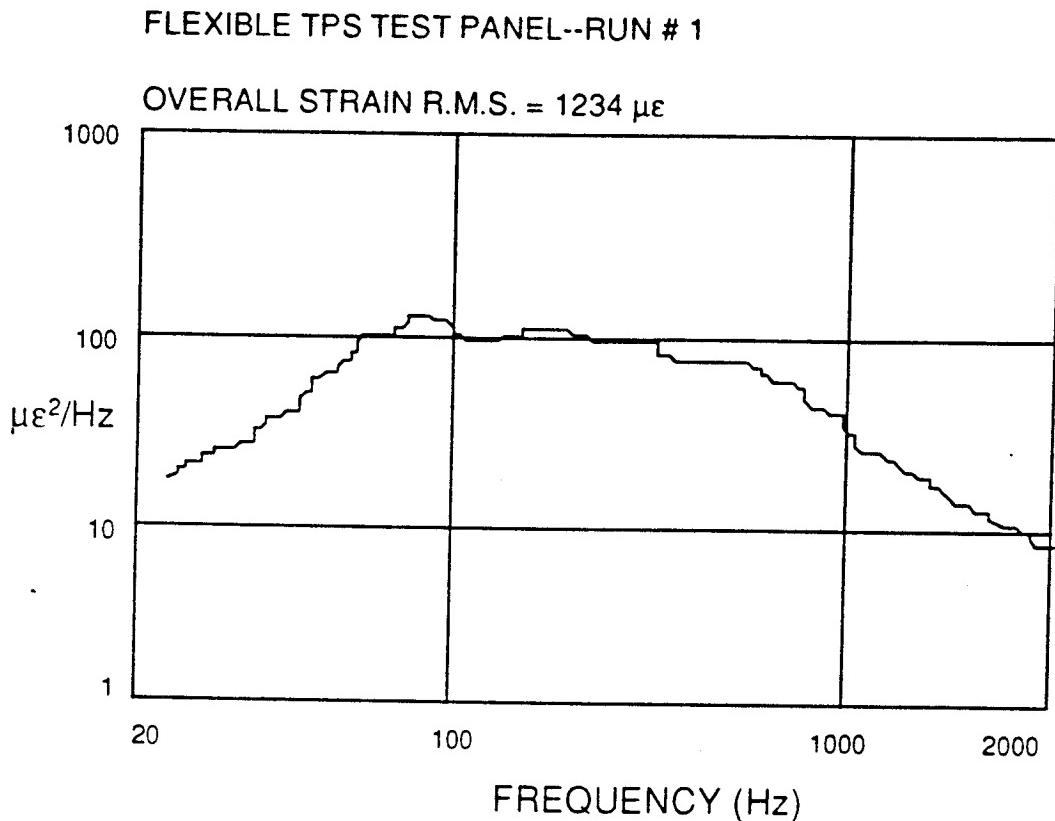


FIGURE 3: Sample Data Sheet for Strain Gauge Data

7.2. DATA FILES

All data for all test runs shall be stored on magnetic media for the duration of the program, or until the test requester concurs that the data can be disposed of.

7.3. TEST REPORT

A White Test Report and copies of all Laboratory Notebook pages shall be prepared and issued to the test requester.

8.0. TEST EQUIPMENT.

The following test equipment will be utilized for the test:

8.1. MECHANICAL SYSTEM.

Vibration test fixture
Shaker (moving element)
Reaction mass
Slip table
Oil Pump
Heat exchanger
Air blower

8.2. ELECTRICAL EXCITATION SYSTEM

Vibration control system analog to digital converters
Power amplifier and magnetic field power supply
Shaker (armature)

8.3. INSTRUMENTATION

Accelerometers
Charge amplifiers
True R.M.S. voltmeter
Other sensors (optional)
Other signal conditioning (optional)
Vibration control system analog to digital converters
F.M. tape recorder (optional)
Digital data acquisition system (optional)

SUB-APPENDIX A: EMERGENCY PROCEDURES

A.1. EMERGENCY PROCEDURES

1. Any member of the test team noting an abnormal condition shall immediately notify the Dynamics Test Engineer or his designated representative, hereinafter referred to as the Test Conductor.
2. The Test Conductor has the sole responsibility to order the excitation removed during test.

A.2. EMERGENCY SHUTDOWN PROCEDURE

1. Upon becoming aware of an abnormal test condition, the Test Conductor shall immediately make a judgment as to whether the excitation level should be reduced or shut down.

*** N O T E ***

IF THE TEST CONDUCTOR AND THE ENGINEERING TEST REQUESTER CONCUR THAT THE ABNORMAL TEST CONDITIONS EXPERIENCED ARE NOT DETRIMENTAL TO THE TEST SPECIMEN AND THAT DATA ACQUISITION AT THAT LEVEL OF EXCITATION WOULD BE ADVANTAGEOUS TO THE TEST OBJECTIVES, THE ABNORMAL TEST CONDITIONS MAY BE IGNORED BY THE TEST CONDUCTOR AND DATA ACQUISITION MAY PROCEED.

2. At any time an emergency exists that requires immediate shutdown, the Test Conductor shall issue an order for the nearest test personnel to reduce the master gain.

APPENDIX J

RADIANT EXPOSURE TESTING

**THERMAL TEST - RADIANT HEAT TEST PROCEDURE
DETAILED TEST PROCEDURE
NRA 8-12, SSTO TA-3**

1.0. OBJECTIVE:

The objective of this test is to obtain thermal performance characteristics of advanced flexible TPS in a radiant heating environment. The test effort involves radiant heat testing at surface temperatures up to 2,000°F.

2.0. SCOPE:

This document describes testing defined in Task 1, 2, & 3 . Changes to this test plan, which are in the scope of the test request, may be made by "redline" changes approved by the test requester and the responsible test engineer.

3.0. APPLICABLE DOCUMENTS:

4.0. TEST SPECIMEN PREPARATION:

Test specimen preparation will be defined in Tasks 1, 2, & 3.

5.0 TEST SETUP DESCRIPTION:

The test articles will be tested in the Rockwell Environmental Simulation and Thermal Physics Laboratory radiant heat facility chamber. The effects of insulating the back face of the test panel with respect to the back face heating rate and the 350F maximum back face temperature are to be established. Insulate the back face of the test panels

6.0. TEST SPECIMEN INSTRUMENTATION:

Three chrom/alumel, Type k 30 GA thermocouples were woven into the outer fabric of the blankets to measure surface temperatures during test. Three of the same type of thermocouples will be symmetrically located and fastened to the back face of each aluminum sheet. One surface instrumented test specimen shall be available for control purposes.

7.0. GENERAL REQUIREMENTS:

1. When handling of the test specimen or any parts of the test article assembly, clean cotton gloves or equivalent shall be worn to prevent alkali contamination. Any physical damage such as accidental surface contamination will be documented in the laboratory notebook and reported to the engineering coordinator.

2. The test requester shall be notified in advance of any scheduled test.
3. Color photographs will be taken before and after each run to document the test article condition.
4. A general visual inspection of the test specimen and fixture shall be made prior to the start of the test. A complete visual inspection after each sequence will be made to determine if any damage had occurred.
5. A test report shall be published at the completion of the test program.

8.0. PROCEDURE:

The Rockwell shall provide the facility apparatus, setup, data acquisition, data reduction, and facility detailed test procedure.

Each bonded blanket specimen shall be exposed to static (constant temperature and pressure) radiant environments combining surface temperatures of 800, 1,100, 1,500 and 2,000F with chamber pressures of 0.076 (or minimum Facility pressure), 7.6 and 760 TORR. Also, each test specimen shall be exposed to three radiant mission profiles with maximum surface temperatures of 1,100, 1,500 and 2,000 F.

9.0. DATA REQUIREMENTS:

All measurements (including temperature and pressure) are to be continuously recorded during the thermal exposure and for a sufficient length of time following the heating to obtain peak internal temperatures and a cool-down trend. Include a minimum of six test article measurements during a test run.

The test data shall be recorded on magnetic tape and strip charts per facility capability. Tabulations and CRT's (computer plots) will be required.

A copy of the data shall be made available to the test requester and the RTE or their representative.

10. TEST ARTICLE DISPOSITION:

The test article shall be returned to Rockwell, Laboratories & Test for retention.

11. APPENDIX:

Chamber schematics
Test article/instrumentation drawing
Temperature/pressure profile

APPENDIX K

VENTING TESTING

**VENTING TEST
DETAILED TEST PROCEDURE
NRA 8-12, SSTO TA-3**

INTRODUCTION

This Detailed Test Procedure (DTP) defines the venting test for the TPS material developed in the different tasks of TA-3. The specimen material, configuration and in venting tube instrumentation will be specified by each task.

OBJECTIVE

The objectives of this test are to determine the differential pressure between ambient and the interior of the test article, the pressure gradient across the interior of the specimen at various depths, and if the material can withstand the differential pressure.

SCOPE

This document contains the test requirement and the detailed test procedures required to conduct the venting test. This test will be conducted at the Rockwell test facility. Changes to this plan which are in the scope of the test request may be made by "Redline" changes approved by the Responsible Test Engineer (RTE)

APPLICABLE DOCUMENTS

- Rockwell Laboratory notebook for recording observations during testing.
- Disposition Record Form for recording test deviations and anomalies during testing.

GENERAL REQUIREMENTS

Documentation

Detailed Test Procedure (DTP)

The test will be conducted in accordance with this procedure.

Laboratory Notebook

A Laboratory Notebook will be maintained by the L&T RTE depicting a complete test history. Test article configuration, instrumentation, test anomalies and malfunctions and all other pertinent data and information will be recorded.

Test Report

The test agency will issue a Laboratory Test Report (LTR). The test report will depict the complete test program, instrumentation, brief test procedures and results, test setup including photographs, test data and other pertinent information.

Notification

The RTE shall be notified in advance of any scheduled test.

Test Facility

The test will be conducted in Bldg. 299, Environmental Systems Laboratory.

Instrumentation

All measurement instrumentation will be calibrated and have a decal showing a valid calibration due date. A list of test instrumentation will be maintained in a Laboratory Notebook showing name/description, metrology number and calibration due date.

Test Conduct

The test program will be conducted under the direction of a test conductor who will be the L&T RTE or his designated representative.

TEST SPECIMEN

Specimen number and material will be defined by each task. the specimens shall be identified and instrumented with pressure tubes. The number of pressure tubes and depths of tubes to be instrumented in the specimen will be defined.

TEST SETUP

See Fig. 1 for instrumentation of pressure tube in the test specimen and Fig. 2 for test system schematic.

Pretest Verification

- Verify that all instrumentation and calibrated equipment are recorded in the Laboratory Notebook.
- Verify that all pressure tubes are properly connected to pressure transducers and the tube is clear and unbent, and reaches the required depth of the specimen.
- Verify that all 13 pressure transducers channels indicate ambient pressure on LDS.
- Photograph test specimens and the test setup.
- Start the diffusion pump per next paragraph.
- O.K. to close the vacuum chamber.

Diffusion Pump Startup

- Verify that the pump cooling water is on.
- Start the foreline pump (FP-1 to the "ON" position).
- Verify that light FP-1 on the system schematic panel is running.
- Open the foreline valve (FV-1 to the "ON" position).
- Verify that light FV-1 on the system schematic panel is illuminated.
- Verify that the foreline pressure decreased to less than 50 microns.
- Turn on the diffusion pump heater (DTP-1 to the "ON" position).
- Verify that light DP-1 on the system schematic panel is illuminated.

TEST PROCEDURES

The ascent and reentry pressure profiles will be defined. See Fig. 3 and 4 for examples of Orbiter profiles.

Ascent Profile

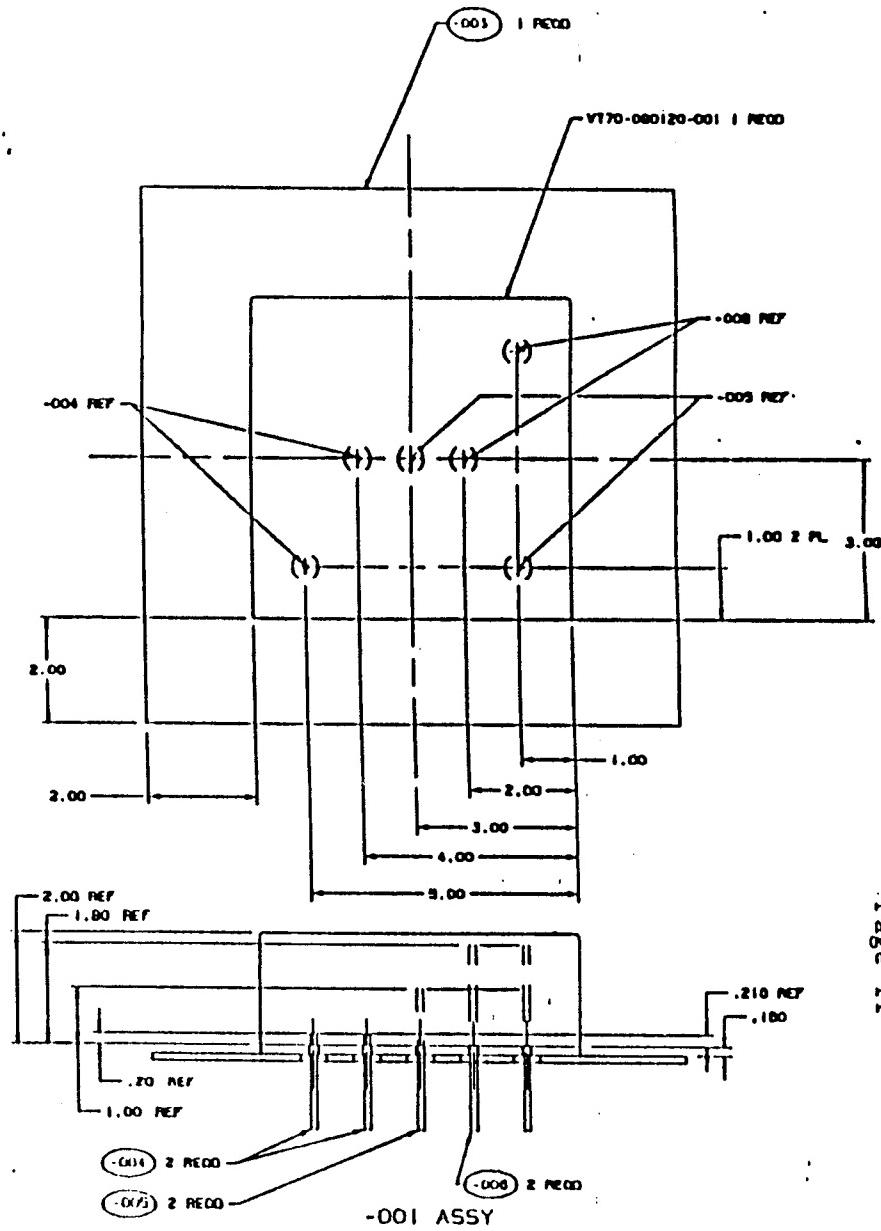
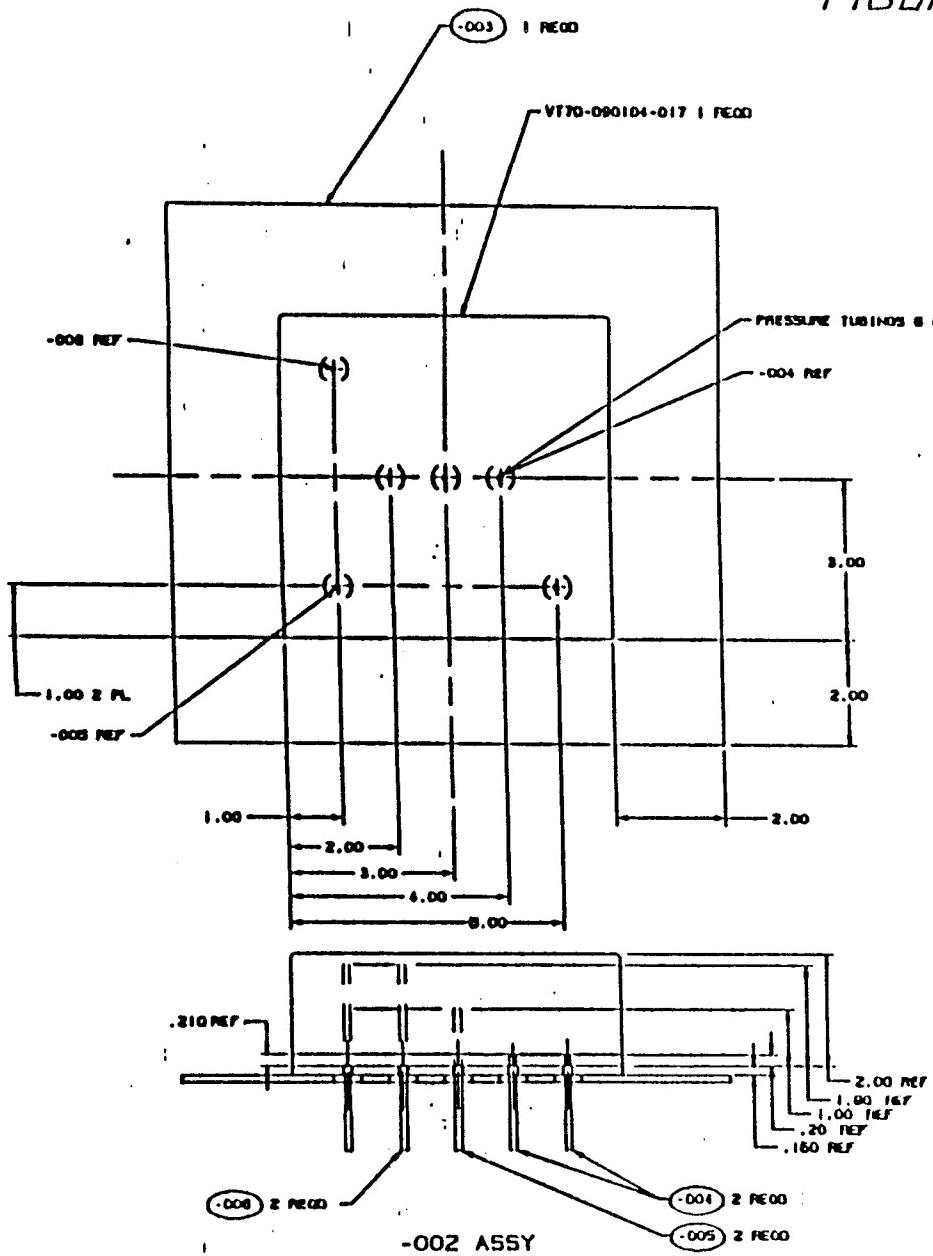
- Verify that the chamber door is closed.
- Verify that the chamber isolation valve is in the "CLOSED" position.
- Verify that the pump position switch is in the "OFF" position.
- Activate the MICON Valve Controller and 28 VDC Power Supply.
- At MICON Valve Controller:
 - Set Computer/Auto/Manual mode select switch to "MANUAL".
 - Set Process Feedback/Error/Valve Command switch to "Valve Command".
 - Verify that lower LED display indicates 00.0% (fully closed position).
(Note: If the display shows other than zero, press Increment/Decrement switch down until the display shows zero.)
 - Set Process Feedback/Error/Valve Command switch to "Valve Command".
 - Verify that lower LED display indicates around 95% (ambient).
- Verify that Data Trak curve following probe is in the ascent profile program starting point.
- Verify/position Data Trak mode select switch to "REMOTE".
- Start the 300 CFM roughing pump.
- Open the chamber isolation valve.
- Set the pump position switch to "PUMP VALVE OPEN".
- Set LDS System at one second sample rate.
- Set Data Trak mode select switch to "RUN".
- Set Computer/Auto/Manual switch to auto at MICON valve controller.
- Verify the proper DATA TRAK operation (Monitor the curve following probe position vs. set point).
- At the completion of the ramp:
 - Set DATA TRAK mode select switch to "RUN"
 - Change LDS sampling rate to 20 second interval.
- Continue to pump down the chamber until the chamber pressure reduces below 50 microns.
- Set Computer/Auto/Manual switch to auto to "MANUAL".
- Set Process Feedback/Error/Valve Command Switch to Valve Command.
- Press Increment/Decrement switch down until lower LED display indicates 0.00%.
- Verify that the diffusion pump is ready for pumping.
- Open the high vacuum valve.
- Reduce the chamber pressure to 10 (-3) torr or lower. Hold for 15 minutes minimum.
- Close the high vacuum valve.
- Proceed to next paragraph to simulate entry pressure profile.

Entry Profile

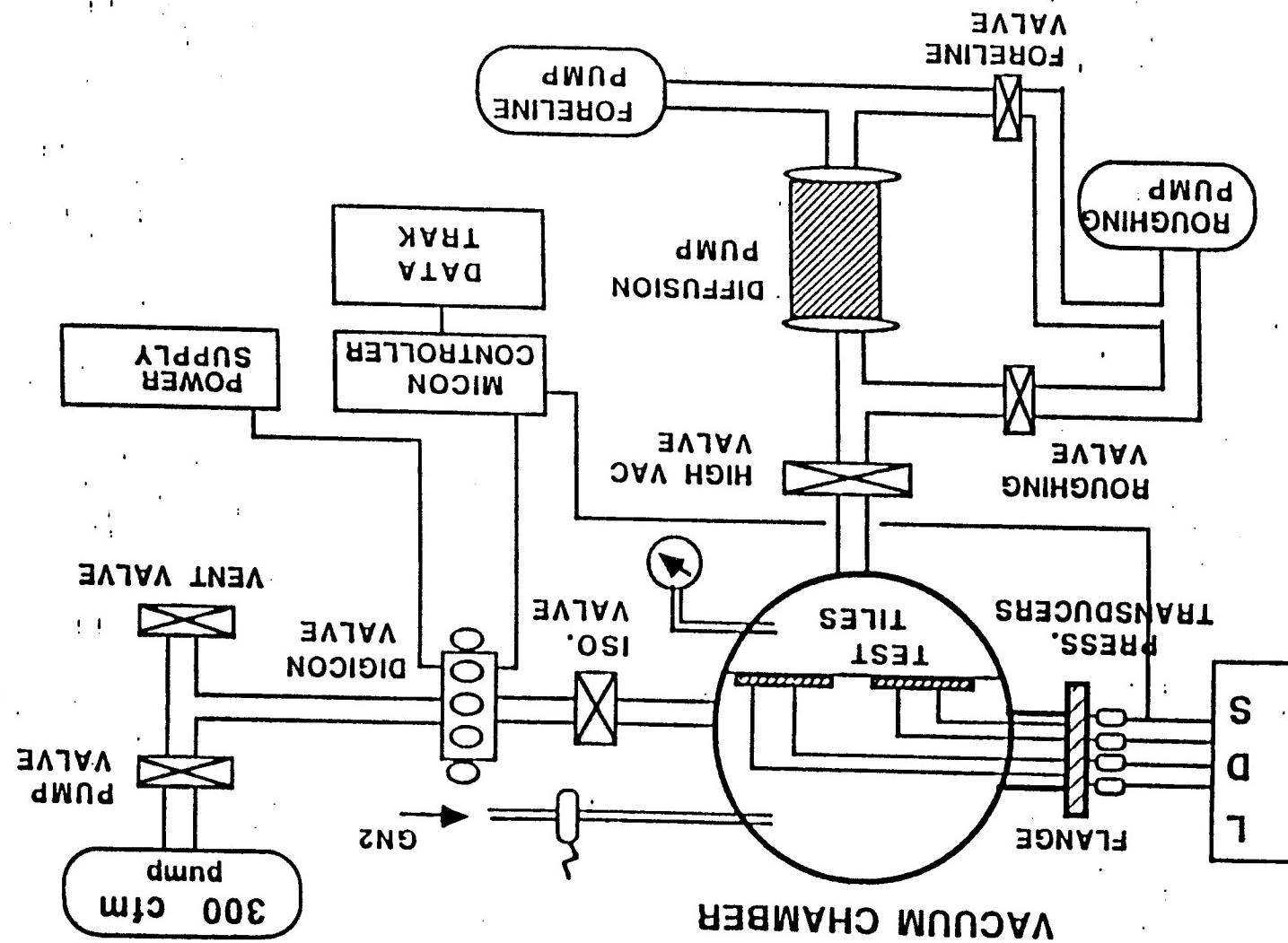
- Verify that DATA TRAK curve following probe is in the entry profile program starting point.
- Verify/Set Computer/Auto/Manual selector to "MANUAL".
- Verify/Set Process Feedback/Error/Valve Command selector to "Valve Command"
- Verify that lower LED display indicates zero (0.00%)

- Set Process Feedback/Error/Valve Command selector to "Process Feedback".
- Activate LDS at one second sample rate.
- Position Data Trak mode selector to "RUN".
- Set Computer/Auto/Manual selector to "AUTO".
- At the completion of the ramp, secure the system as follows:
Set Data Trak mode select switch to "HOLD".
Set Computer/Auto/Manual switch to "MANUAL".
Set Process Feedback/Error/Valve Command switch to "VALVE COMMAND".
Verify that lower LED display indicates zero.
Verify that the pump position switch to "PUMP VALVE CLOSE". (ambient)
Turn off the 300 CFM roughing pump.

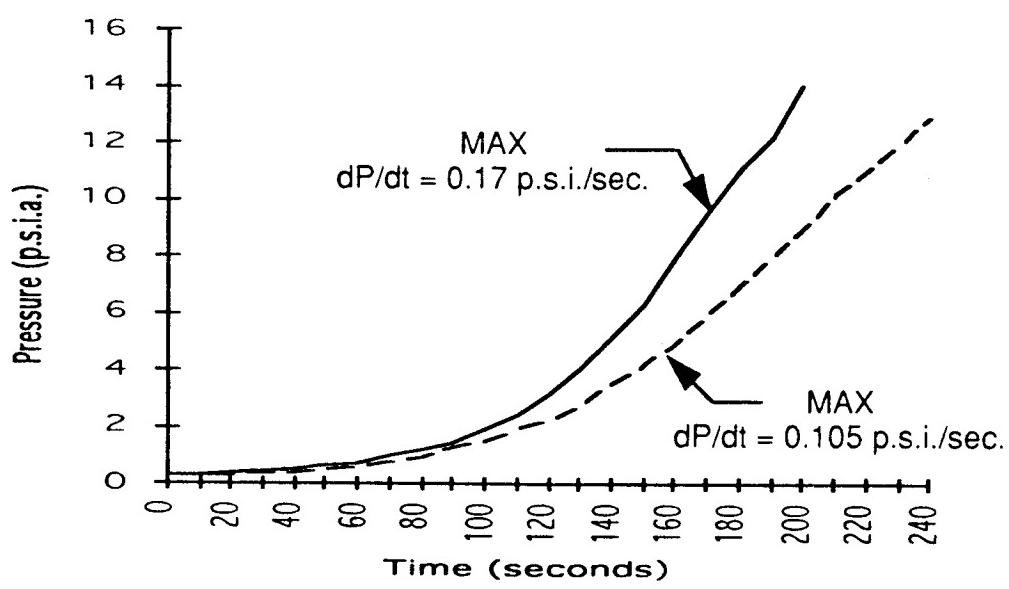
TEST S. ECIMENS
FIGURE 1



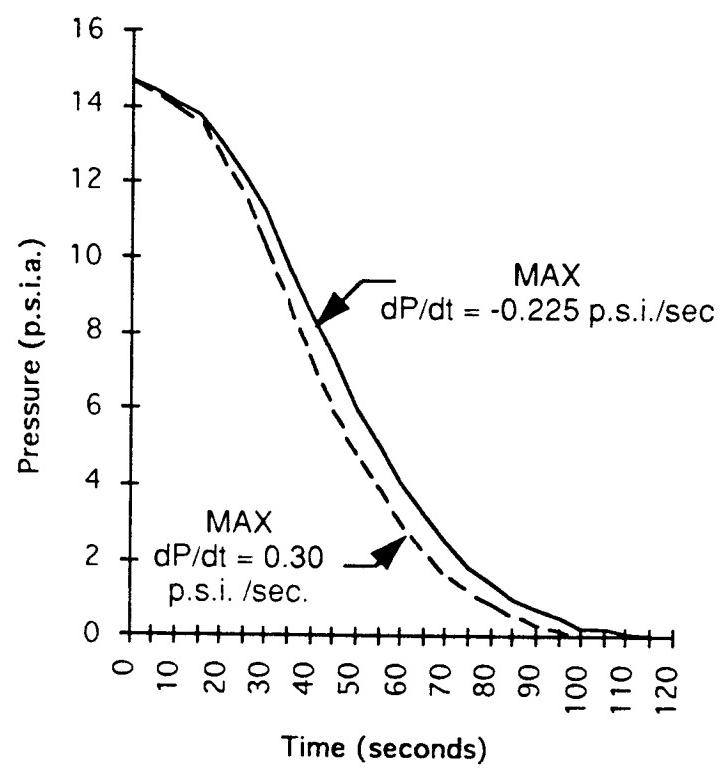
DTP 5346-801
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MISSION ENTRY: Ambient Pressure Boundaries



**MISSION ASCENT: Ambient
Pressure Boundaries**



APPENDIX L

AIR IMPINGEMENT TESTING

**AIR IMPINGEMENT TEST
DETAIL TEST PROCEDURE
NRA 8-12, SSTO TA-3**

OPERATING PROCEDURE FOR AIR IMPINGEMENT TEST APPARATUS

The following procedure stipulates guidelines for the system operation and performance of the air impingement test apparatus.

I. Test Parameters: The following test parameters are in general used for establishing test conditions of the upstream jet stream and its relative direction prior to impact at the surface of the test coupons.

I.1 Scenario one - Continuous jet stream impingement.

This scenario simulates a continuous bombardment of air jet stream on the surface of the test coupon under the following conditions:

Test variable parameters:

1. Angle of impingement () - relative angle of impingement between the upstream jet direction with respect to the orientation of the planar surface of the test coupon.

Note: The upstream jet is defined as the jet stream prior to impact.

2. The exit velocity of the jet stream (V) - the velocity of the jet stream as it exits the nozzle. Since it is difficult to directly measure this parameter, it is usually calculated based on the following measurable quantities:

- Exit pressure
- Supply pressure
- Volumetric flow rate
- Cross-sectional area at the exit of the nozzle
- Cross-sectional area at the supply line

I.2 Scenario two - Intermittent air stream impingement

This scenario simulates a pulsing effect of air jet impingement on the surface of the test coupons which exerts a stronger aerodynamic loading on the surface of the test coupons than that of scenario one.

All the required parameters are the same as before with one additional parameter (the speed of the chopper) which is usually expressed in terms of frequency, Hz. The chopper is positioned between the upstream jet stream and the test coupon.

II. Procedure

1. Select the specific gas as a working fluid. The most commonly used gas is air. For short duration (less than 30 minutes), plant air can be used. For long duration (greater than 30 minutes), it is recommended that dry air or gaseous nitrogen be used. Plant air is always contaminated with oil, and as a result the oil particles will be deposited onto the surface of the test coupons upon impact. Using gaseous nitrogen or dry air will eliminate the oil contamination.
2. Determine the angle of impingement. This angle is obtained from the actual situation.
3. Determine the configuration of the nozzle to be used.

The configuration of the nozzle depends upon the size of test coupon, the required test conditions, etc. However, it is limited by the adaptability to the existing test apparatus. The range of nozzle size is from 1/4 -inch to 1-inch diameter tube.

4. Evaluate the required differential pressure between the supply line and the nozzle exit from the given exit stream conditions, nozzle configuration, supply line size and pressure, and appropriate flow range.
5. From the known supply pressure, obtain the appropriate pressure range for the exit analog pressure gage.

Note: For safety purpose, it is required that the desired range for the analog pressure gage should be twice the maximum measured pressure.

6. Similarly, select the appropriate pressure range for the supply pressure gage based on the known supply pressure.
7. Install a relief valve downstream of the supply pressure gage to protect the hardware from exploding in case of an accidental over pressurization.

8. Mount the nozzle to the exit of the test apparatus.
9. Install test coupon to an adjustable test platform which is equipped with three-dimensional adjustments.
- 10 Rigidly secure the test coupons to the platform.
11. Select two rectangular bar strips whose thickness is approximately 1/4 inch.
12. Insert two rectangular bar along the length of the test coupon with a spacing approximately the length of the nozzle.
13. Overlay an 1/8 inch Plexiglas over the bar strips and securely clamp the entire assembly to the platform.

Note: The complete assembly will have a rectangular channel run longitudinally along the test coupon. This channel provides a guide for the flow of jet stream after impingement.

14. Position the nozzle to align with the channel (step 12) on the test coupon.
15. Adjust the direction of the platform with respect to the nozzle orientation to meet the required angle of impingement.
16. Adjust the lateral direction to make sure it is horizontal..
17. Set the chopper frequency:
 - There is no direct indication of the frequency (speed) of the chopper during operation. However, an indirect way of setting the frequency is using stroboscope.
 - Scribe a radial line on the back face of the chopper.
 - Loosen the thumb nut which secures the shaft to the motor.
 - Convert the required frequency from Hertz into RPM which is the unit registered on the dial of the stroboscope.
 - Set the required RPM on the dial.

- Position the stroboscope with the flashed light point toward the scribed mark on the chopper surface.
 - Turn the power on to the chopper.
 - Adjust the thumb nut and locate the scribed mark on the chopper.
 - The chopper frequency will be achieved when the scribed mark remains stationary with respect to you.
 - Secure the thumb nut to lock in the desired setting for the chopper.
 - Remove the stroboscope.
 - Leave the chopper rotating
18. Since the test coupon will be exposed to the desired condition instantaneously, it is recommended that a shield is placed in front of the exit jet stream to deflect the jet stream away from impacting the test coupon.
19. With the shield in the way, gradually regulate the supply air to produce the required exit test condition.
20. Verify that the required test conditions from the instrumentation outputs.
21. Remove the shield when the test conditions were achieved and simultaneously start the timer.
22. Allow the air to flow for a predetermined test duration or until failure whichever is required.